# A MATTER OF TRUST 2.0

FORD'S APPROACH TO DEVELOPING SELF-DRIVING VEHICLES

Updated June 2021

# OUR PURPOSE

OUR PURPOSE IS TO HELP BUILD A BETTER WORLD, WHERE EVERY PERSON IS FREE TO MOVE AND PURSUE THEIR DREAMS.

# TRUST CONTINUES TO BE OUR GUIDING PRINCIPLE


**AT FORD**, we are building a self-driving service for ride hailing and goods delivery. Our goal? To ultimately make people's lives better by providing a safe, trusted and affordable mobility solution.

We know that the services enabled by self-driving technology will be nothing without establishing trust among the cities and people we serve. And, building trust while treating customers like family has been at the heart of what we do since 1903. Over the last century, Ford has designed vehicles with the customer at the center and manufactured safe, quality vehicles at high volumes to meet the needs of people all over the world. We've taken the same approach with building our self-driving business — working closely with cities, neighborhoods and the people who live in them to establish trust in an entirely new way to move.

Since our safety report was first released in 2018, we have been bringing together all of the complex pieces needed to launch a self-driving service—the vehicle is just one part of the broader picture. We have also been developing a robust Automated Driving System (ADS) with our technology partner Argo AI; building an exceptional customer experience; the transportation-as-a-service (TaaS) software; and our fleet operations expertise—which will be key to a trusted, reliable service; as well as collaborating with government partners at a federal, state and local level to apply this technology to help solve the mobility challenges cities face.

In 2018, Ford announced Miami, Florida, would serve as our launch city for self-driving services. Since then, we have established operations to launch our services in two additional cities: Austin, Texas; and Washington, DC. Not only have each of these cities become proving grounds for building our business and testing our technology, they have become home for us. In addition to our three launch cities, we are also testing the ADS with Argo AI in Detroit, Michigan; Palo Alto, California; and Pittsburgh, Pennsylvania. With testing being conducted in six markets, Ford and Argo AI have what may be the largest, most diverse active urban-testing footprint of any self-driving vehicle developer. Testing in multiple cities is important to building a self-driving service because it exposes the ADS to a variety of complex scenarios, behaviors and imagery, enabling the system to be able to scale quickly.

Our goal is to continue to be transparent about the services we are building, and the impact they will have in our cities. Through this Voluntary Safety Self-Assessment (VSSA) report, you will learn about the progress we are making and our continued commitment to building these services in a safe and trusted manner.

**Self-Driving Defined:** Throughout the VSSA we use the term "self-driving vehicle" to refer to a vehicle equipped with a Level 4 or Level 5 Automated Driving System (ADS). The terms Automated Driving System (ADS), Self-Driving System (SDS) and Virtual Driver System (VDS) have been used interchangeably in the past. Ford has decided to align with the Society for Automotive Engineering (SAE) J3016 standard's usage of Automated Driving System, or ADS. Argo AI continues to refer to its system as Argo AI's SDS.

**Dive Deeper + Stay Connected:** You can dive deeper and continue to stay connected, as we launch our services by checking out Ford's Self-Driven blog: https://medium.com/self-driven and Argo AI's Ground Truth blog: https://groundtruthautonomy.com/.

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# Our Technology Partner:
# ARGO AI

Argo AI is an artificial intelligence and robotics company, led by some of the industry's most experienced self-driving vehicle experts. Ford is working with Argo AI to develop the "brains and senses," or what Argo refers to as the Self-Driving System (SDS), for our self-driving vehicles.

Argo AI is applying the latest advancements in computer vision and machine learning to help build safe and effective self-driving vehicles. The team also has extensive experience in commercializing robotics and sensing technologies with a history of designing and deploying integrated systems.

With their global headquarters in Pittsburgh, PA, and engineering centers in Palo Alto, CA; Detroit, MI; Cranbury, NJ; and Munich, Germany, the 1,300 people on staff come from diverse educational backgrounds with a high concentration of Master's and PhD degrees. To foster continued learning and enable the roboticists of tomorrow, Argo AI has formed research collaborations with Carnegie Mellon University and Georgia Institute of Technology.

Argo AI's ability to build a scalable software architecture with production-quality code from the start plus Ford's expertise with vehicle integration and manufacturing give us the confidence to build high-quality self-driving vehicles. This unique partnership unites the benefits of a technology start-up with the experience and discipline of an automaker.

*You can read more about Argo AI and their safety report here, as well as their Ground Truth blog: https://groundtruthautonomy.com/.*


Ford refers to Argo's SDS as the Automated Driving System (ADS)

# FORD'S HISTORY WITH AUTOMATED DRIVING AND DRIVER-ASSIST TECHNOLOGIES

Ford has a long history of research, development and commercialization of driving automation systems, although we've clearly split them into dual pathways depending on how the technology is applied for customers. While this report is focused on describing our approach to SAE J3016 Level 4 self-driving or ADSs, the timeline highlights when some of our active safety systems and driver-assist[1] technologies were introduced to the Ford and Lincoln portfolios.

We use the term driver-assist technology to describe features that assist drivers with convenience or safety benefits, but they are not autonomous because they require the human driver to always remain engaged and available to take control of the vehicle. These features are defined by SAE J3016 as Levels 0-2 of automation, which leverage technology to augment a human driver but not replace them. For instance, the blind spot information system uses radar technology to detect if there is a vehicle in a driver's blind spot, thus augmenting their ability to look and see for themselves.

**Active Safety and Driver-Assist Technology Milestones**

- **2006**: Adaptive Cruise Control
- **2007**: Blind Spot Information System (BLIS)
- **2008**: Lane departure warning
- **2009**: Active park assist
- **2010**: Forward Collision Warning with Brake Support
- **2011**: Curve Control
- **2015**: Pre-Collision Assist with Pedestrian Detection; 360-degree view camera
- **2016**: Pro Trailer Backup Assist
- **2017**: Adaptive cruise control with stop-and-go
- **2018**: Ford introduces Co-Pilot360, the most comprehensive standard active safety and driver-assist technology package available with Post-Collision Braking, Evasive Steering Assist and Lane Centering
- **2020**: Ford Active Drive Assist

**Self-Driving Research + Development Milestones**

- **2004**: Ford employees volunteer at DARPA Grand Challenge to research technology potential to improve safety
- **2005**: Ford enters DARPA Grand Challenge with a self-driving Ford F-250 Super Duty and qualifies for the finals
- **2007**: Ford reaches the finals at the DARPA Urban Challenge
- **2009**: Launch of fleet of ten Fusion Hybrid Autonomous Research Vehicles for testing and development
- **2012**: Ford begins testing self-driving vehicles on public roads in Michigan
- **2015**: Ford secures a license to test self-driving vehicles in California and opens its Palo Alto Research and Innovation Center

  Beginning of testing at Mcity
- **2016**: Announces plan to launch commercial service in 2021
- **2017**: Investment and partnership with Argo AI for ADS development

  Partners with Domino's Pizza and Lyft to begin testing of self-driving customer experience
- **2018**: Launch of self-driving business operations in Miami

  Expansion of self-driving business operations in Washington, DC

  Partners with Postmates and Walmart to research self-driving delivery experience
- **2019**: Launch of self-driving business operations in Austin
- **2020**: Reveals fourth-generation test vehicle and launch vehicle platform: Escape Hybrid

  Launches moving goods pilot in Miami with first integration of Argo AI's self-driving capabilities with Ford's customer-facing partnerships.

  Installs first Ford-designed smart node in Saline, Michigan, to begin researching complex intersections

  Given the impact of COVID-19 on consumer behavior, Ford shifts commercial service launch to 2022
- **2021**: Installs first Ford-designed smart node in Miami

  Integrating fourth-generation Escape Hybrid test vehicle into fleets

[1]SAE now refers to Level 1 and Level 2 driving automation systems as "driver support features" as of the SAE J3016 2021-04 release.
https://www.sae.org/news/press-room/2021/05/sae-international-and-iso-collaborate-to-update-and-refine-industry-recognized-sae-levels-of-driving-automation

# FREQUENTLY ASKED QUESTIONS: FORD'S SELF-DRIVING SERVICE

## WHAT DOES FORD MEAN BY SELF-DRIVING VEHICLE?

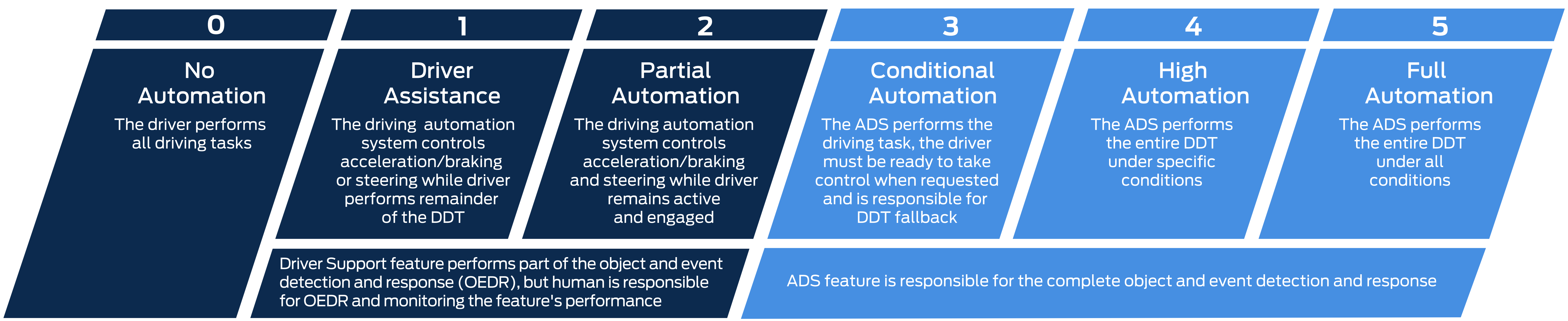
Today, customers can benefit from experiencing automation systems that enhance safety or convenience in cars they can buy now. We call these features driver-assistance or partial automation, because they are designed to help improve the driving experience for a human driver and are set by the SAE International (SAE J3016) as Level 0-2. You may have heard of some of these features such as blind spot monitoring, lane keeping assist and adaptive cruise control. To be clear, these are not "self-driving" or "autonomous"—and we will never refer to them as such—because they require the human driver to supervise and maintain control of the vehicle.

We use the term "self-driving vehicle" to refer to a vehicle equipped with an Automated Driving System (ADS) that meets the definition set by the SAE J3016 for Level 4 or Level 5 automation. The self-driving feature of our vehicle will be Level 4, meaning the ADS is capable of performing the dynamic driving task (DDT) without the need for a driver under specific conditions (known as an Operational Design Domain, or ODD – *see page 28 for details*). When the ADS is engaged, it has full responsibility for the task of driving.

## WHAT DO YOU MEAN BY ADS?

To make SAE J3016 defined Level 4-capable autonomous vehicles, which do not need a driver to take control, the car must be able to perform what a human can perform behind the wheel. Our ADS is designed to do just that, with the help of:

- Sensors — lidar, cameras and radar to "see" all around the vehicle
- Algorithms running on powerful computers to determine the traffic situation all around the vehicle and plan where to go next
- Highly detailed 3D maps
- Precise inertial measurement systems




SOURCE: The SAE J3016 standard - Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems

# FREQUENTLY ASKED QUESTIONS: FORD'S SELF-DRIVING SERVICE

## WILL FORD'S SELF-DRIVING SERVICE BE TRULY DRIVERLESS?

Yes, our self-driving service will eventually operate without the need for a driver or test specialist within a defined geo-fence service operations area. For our testing, we use test specialists who are responsible for monitoring the road ahead and monitoring the performance of the ADS.

## WHEN WILL FORD REMOVE THE SAFETY OPERATOR?

We are not in a race to remove the safety operator, which Ford and Argo refer to as test specialists – we are focused on doing this correctly and safely. We will work with Argo AI to assess the need for the test specialist and make a decision based on applicable regulations, safety performance milestones of the ADS, an appropriate level of community acceptance, and other factors to enable truly driverless operation within our defined service operation area.

## WHEN AM I GOING TO BE ABLE TO EXPERIENCE FORD'S SERVICE?

Ford and our technology partner Argo AI are currently testing with our self-driving vehicles on public roads with test specialists. Therefore, you might read about or see our self-driving vehicle operating on city streets as we are testing. Ford is also building our business to move both people and goods in parallel. To do this, Ford will conduct business pilots for ride-hailing and goods delivery services; build our customer experience and fleet operations to ensure our vehicles are utilized and sanitized; and continue to collaborate with the local communities.

ADS: Automated Driving System

We plan to launch our initial self-driving service in Austin, Miami and Washington, DC, in defined geo-fenced areas with plans to expand to additional cities. If you are within these areas you could potentially use Ford's service.

Over the next few years, Ford will continue to build its business and work with Argo AI to develop the ADS across multiple dynamic cities across the U.S. like Austin, Miami and Washington, DC. You can stay up to date on our business plans and latest news on our Self-Driven blog at medium.com/self-driven.

## CAN I BUY A FORD SELF-DRIVING VEHICLE?

No, our self-driving vehicles won't initially be sold to customers in the way that cars are today. We believe we can offer the best value to our customers by providing the technology through a fleet service, similar to the way Ford currently offers specially engineered vehicles for taxi and police fleets. You'll be able to experience these vehicles through a ride-hailing or goods delivery service.

## WHAT VEHICLE WILL FORD USE TO LAUNCH ITS SELF-DRIVING SERVICE WITH?

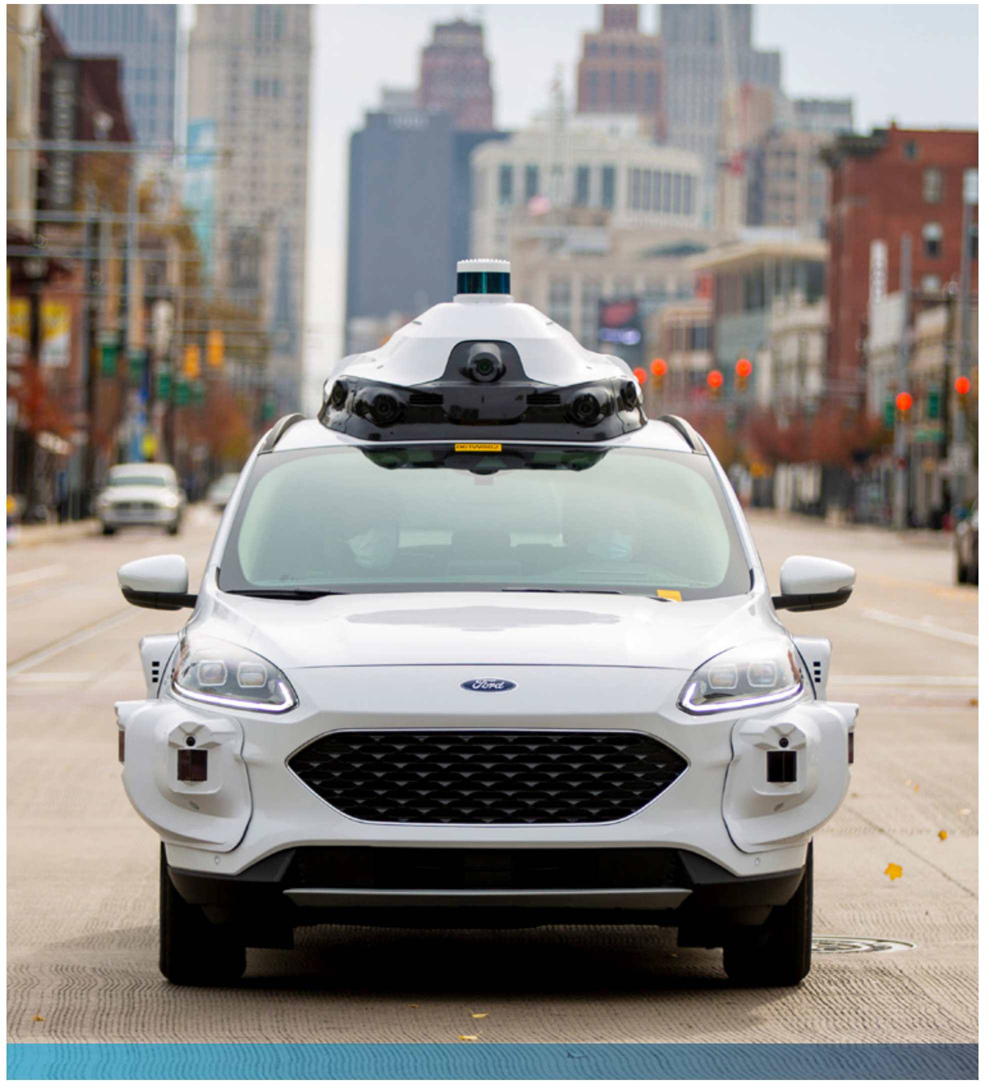
The vehicle platform and architecture customers can expect to see when we bring our service online is the Escape Hybrid. The team will modify the exterior and interior of the vehicle to build a safe and customer-centered experience – whether someone is having a package delivered or hailing a ride.

## WILL THE INTERIOR LOOK LIKE THE ESCAPE DOES TODAY?

No. We will be modifying the interior to build the best experience to move both people and goods.

## WHY IS FORD LAUNCHING A SERVICE WITH A HYBRID VS. AN ALL-ELECTRIC VEHICLE?

Ford envisions a future where our self-driving vehicles are all-electric, but we also need to find the right balance that will help develop a profitable, viable business model. The current state of battery technology doesn't support our business or utilization model. While we will launch with a hybrid platform initially, we will progress to an all-electric platform as soon as it is viable for the business.



# FREQUENTLY ASKED QUESTIONS: FORD'S SELF-DRIVING SERVICE

## HOW IS FORD WORKING WITH THE BROADER INDUSTRY TO COLLABORATE TO SAFELY LAUNCH ITS SERVICE?

Ford is a member of several business associations and consortiums whose members are also testing self-driving vehicle technologies. Some of these groups work with lawmakers, regulators, and the public to realize the safety and societal benefits of fully self-driving vehicles, while others seek to educate the public about autonomous technologies. Additionally, Ford participates in various consortiums addressing the safety challenges self-driving vehicles face through the development of industry best practices and standards (*see page 15 for more details*).

Ford is also actively seeking a federal framework that will promote safety and innovation in the self-driving vehicle space. This is critically important to the future of mobility by building public trust in these technologies and ensuring our country's competitiveness in this new automotive era.

Among our ongoing autonomous vehicle (AV) regulatory and policy efforts are the Alliance for Automotive Innovation and the Self-Driving Coalition for Safer Streets, where we are working with industry to advocate for the safe and expeditious deployment of AVs while promoting the benefits of the technology.

In 2021, Ford joined the National Highway Traffic Safety Administration's (NHTSA) AV Test Initiative. Through this voluntary initiative, NHTSA aims to provide an interactive tool that will keep the public up to date on the states and companies using ADS technology on public roads, and we will support by sharing details about our self-driving vehicles, testing and operations.

ADS: Automated Driving System
SOURCE: https://www.selfdrivingcoalition.org/about

## I LOVE TO DRIVE. WHY WOULD I WANT TO USE A SELF-DRIVING SERVICE?

Building cars and trucks that are fun to drive is at the heart of what we do at Ford, and we're not going to stop any time soon. But, we believe there are many benefits to using a self-driving service for ride-hailing including increased flexibility, control and freedom to make changes before or during your trip; control over having a private environment, providing increased productivity; and most importantly increased safety. Our technology will focus initially on urban areas where vehicle ownership is challenging and expensive, so our service will complement, not conflict. It can ultimately provide value and a consistent, enjoyable experience.

## WILL SELF-DRIVING VEHICLES IMPROVE SAFETY?

The U.S. Department of Transportation has projected that self-driving vehicles could significantly reduce the severity and frequency of crashes and fatalities. We believe that both the safety technology that we offer on our vehicles today and the self-driving vehicles of the future, have the potential to reduce accidents and injuries and save lives. But while we see tremendous potential in these technologies, they are not our only solutions. We continue to improve upon the design of our vehicles to ensure protection of all our passengers. We offer technologies to reduce distractions, like voice-enabled SYNC, and enable emergency services, like 911 Assist, which can help connect you to emergency services when you need it. And we work to improve road safety through driver education and training, like our Driving Skills for Life program.

## WILL SELF-DRIVING CARS "SOLVE" CONGESTION IN OUR CITIES?

There's no one silver bullet for the problem of urban congestion, so we're working on comprehensive solutions rather than thinking self-driving vehicles alone will solve traffic congestion. We believe self-driving vehicles will be part of that larger solution. For instance, we believe self-driving vehicles have the potential to decrease the number of vehicles required on the road to move people and goods. In addition, their ability to access road information in real-time could help them take more efficient routes.

## WILL PEDESTRIANS BE SAFE LIVING IN A CITY WITH SELF-DRIVING CARS?

Self-driving vehicles should enable safer streets for everyone, including cyclists and pedestrians, not just those utilizing a vehicle. The ADS is constantly surveying its surroundings taking into account pedestrians, cyclists and other road users to predict how to best react. In fact, our perception system can detect, track and classify things on the road – including pedestrians, strollers, cyclists, mopeds and more.

# FREQUENTLY ASKED QUESTIONS: FORD AND ARGO AI TESTING


### HOW DO FORD AND ARGO AI TEST AUTONOMOUSLY?

Before operating autonomously on public roads, Argo AI maps the roads where it intends to test to build the ADS's knowledge of the area. The map includes information such as traffic signals, speed limits and bike lanes. The team then conducts a rigorous testing method – including simulation testing and closed-course driving on a test track, and then the test specialists take the vehicle on public roads to safely test.

### HOW ARE FORD AND ARGO AI SAFELY TESTING?

Ford and Argo AI currently have test specialists in each vehicle – a driver and a co-driver. The driver in the left-seat is responsible for safely operating the vehicle by focusing on the road to monitor for pedestrians and other immediate objects external to the test vehicle. The co-driver in the right-seat maintains focus on a laptop that displays what the ADS's sensors "see" to communicate and coordinate with the driver. As the ADS matures, it will meet safety performance milestones that will eventually enable reduction to a single driver, and eventually, driverless operation within its operational design domain.

### HOW ARE FORD AND ARGO AI CONFIDENT THAT TEST DRIVERS WILL INTERVENE WHILE OPERATING AUTONOMOUSLY ON PUBLIC ROADS?

The test specialists are highly trained and go through a rigorous training program, developed in partnership with Argo AI. The program improves manual-driving skills in the classroom and then verifies those skills driving on closed courses. Vehicle operator training also provides education on self-driving technology. The training program is designed to be difficult and requires candidates to pass tests to advance through each phase.

### DO FORD'S SELF-DRIVING VEHICLES OPERATE IN SCHOOL ZONES?

Yes. Working closely with city officials and schools to clearly communicate our operations, Ford and Argo AI's self-driving vehicles can operate in school zones.

### WHERE ARE FORD AND ARGO AI TESTING?

Ford and Argo AI are testing across six U.S. cities, including: Austin, Detroit, Miami, Palo Alto, Pittsburgh and Washington, DC.

### WHY IS IT IMPORTANT TO TEST IN MULTIPLE CITIES? WHY NOT JUST TEST IN ONE TO TWO CITIES?

Argo AI has what may be the largest, diverse active urban-testing footprint of any self-driving vehicle developer. This is important because it exposes the ADS to a variety of complex scenarios, behaviors and imagery, making it safer and enabling the system to be able to scale or grow more quickly.

*Additional information about how Argo AI tests can be found at https://www.argo.ai/how-we-test/.*

ADS: Automated Driving System

# MOBILITY SERVICES FOR PEOPLE AND CITIES

We recognize that just inserting new mobility technologies and services into a city or neighborhood won't solve its existing challenges and may even make them worse. That is why we are committed to collaborating with city leaders where we operate. We are learning how each city works, what its needs are, and how our technology can help adapt and support each city's unique transportation system. If applied correctly, new technologies can enable solutions to help improve the quality of life for everyone by providing additional access to transportation. We're developing a portfolio of solutions that can help a city improve its transportation system and the ever-growing mobility options emerging every day.

Self-driving services is one part of the solution to help improve mobility. For example, Ford-owned Spin partners with cities, campuses and community groups to provide dockless e-scooter micromobility services in the U.S. and in Europe. Also, Ford's Safety Insights platform tool, available through StreetLight Data's platform, uses machine learning to combine crash data, proprietary vehicle data, and traffic volume data to help cities identify streets and intersections that could be improved to increase safety. Finally, Ford's TransLoc provides technology solutions and orchestration software to transit providers in municipalities, universities, airports, hospitality and private business campuses.

As we develop our mobility solutions, we aren't ignoring how the COVID-19 pandemic has changed the world, including how people work and shop. Prior to the pandemic, many urban centers were dealing with record levels of traffic and pollution, and we began to see a shift from individual vehicle ownership to increased individual and shared mobility services. Due to the pandemic, we have seen a shift in consumer behavior, including a dramatic shift in people's willingness to embrace goods delivery. In a June 2020 report, consulting firm Accenture found an increase of consumers using home delivery services with 45% saying they expect to continue to do so. In terms of shared mobility, now more than ever before, consumers are looking for a safe and sanitary environment.

Coming out of a pandemic, our self-driving service fleet operations are going to be more important as people will likely continue to be wary of gathering in large numbers or in small spaces for some time. Understanding how people view mobility services will be critical to incorporating the right elements into our user experience – and that is one of the many things we are looking at as we build a safe service. No matter what, we will want to put people's minds at ease by making sure they know they, or their packages, are in a safe and protected environment when they get in our vehicles.

At Ford, we tend to think these changes will not simply go away as the virus subsides. Whether permanent or temporary, a change in customer behavior is something we cannot ignore as we build mobility services designed around people's needs.

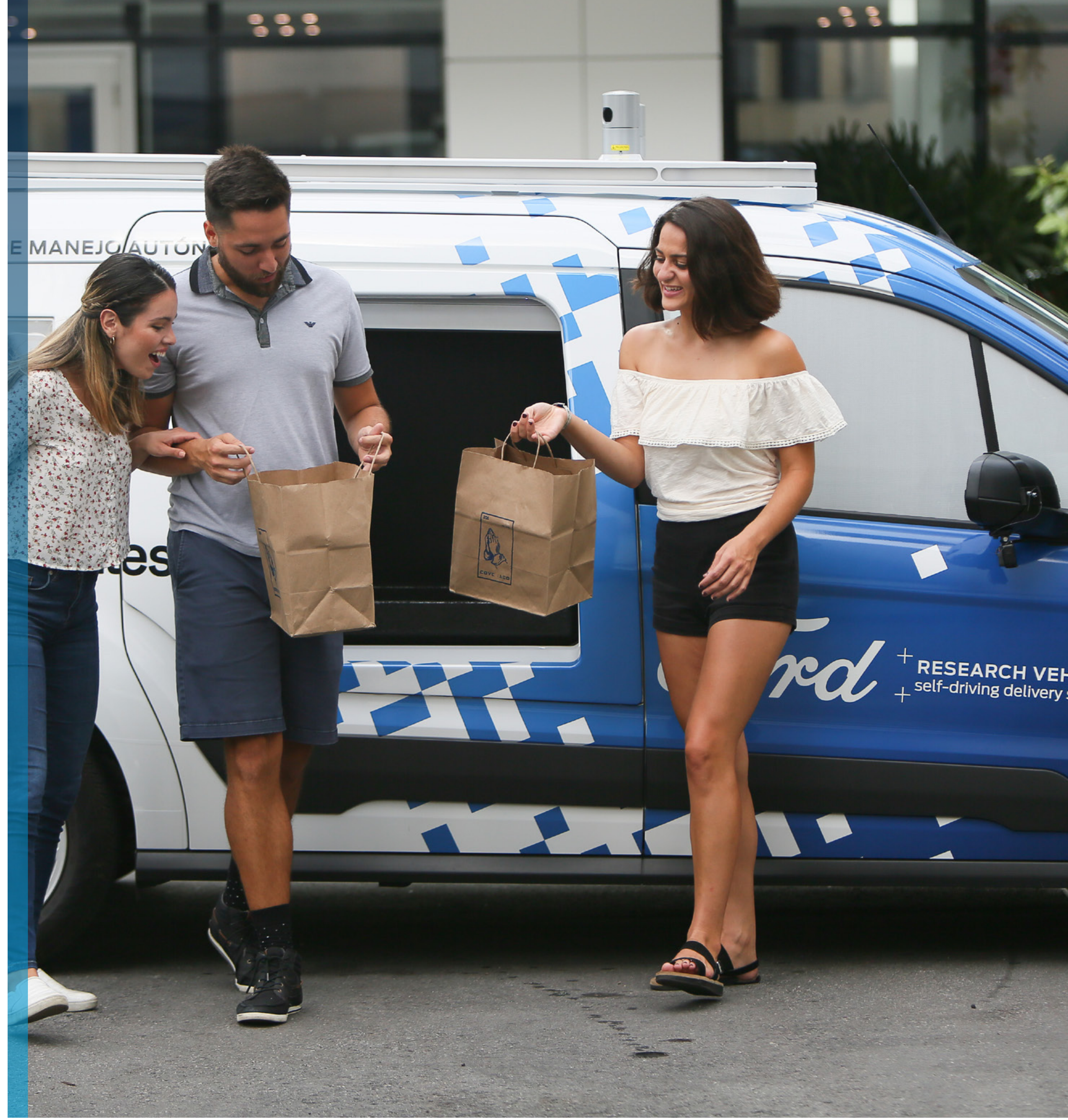
# WHAT OUR SELF-DRIVING VEHICLES WILL ENABLE

To understand the potential ways to use self-driving vehicles, we must first think about them in a different way from how most of us use cars and trucks today. Initially, self-driving vehicles will work best to move people and goods using a different business model – one where vehicles are accessed and shared as a service versus owned and driven.

We think self-driving vehicles can enhance mobility services by being more accessible, affordable and by complementing a city's existing transportation ecosystem. For example, these services could provide a solution for people who may not be able to drive themselves or provide a last-mile solution for a commuter. In the realm of goods delivery, we see an opportunity to help with the increasing demand generated by the convenience of ordering from retailers or supporting a business to provide additional ways to move goods. As they reach scale, self-driving vehicles have the potential to transform cities in countless ways – including improving safety, reducing congestion and making people's lives better.

Furthermore, people will have an opportunity to hail self-driving rides to avoid parking costs and reduce traffic frustrations, while shoppers will seek efficient, effortless delivery via self-driving services. We believe that people and packages can move more safely, efficiently and affordably in the self-driving future.

SOURCE: https://www.selfdrivingcoalition.org/



# HOW OUR SELF-DRIVING VEHICLES WORK

For an ADS to achieve capabilities similar to a human, our test vehicles are fit with the latest in cutting-edge sensing and computing technology. Yet, the components that make up the vehicle itself—such as the suspension, brakes and electrical system—are also critical because a self-driving vehicle must be designed and developed as an integrated system that works in unison. Otherwise, we're not able to achieve the needed performance levels capably and reliably. Today, we're testing with our third-generation Ford Fusion Hybrid and our fourth generation Ford Escape Hybrid self-driving test vehicles.

Each vehicle is equipped with hardware that make up the ADS. This system is responsible for the perception, motion planning and controls, which together enable the vehicle to drive itself, including planning a route, detecting and tracking objects, and anticipating how other road users will behave.

- The perception system is made up of sensors including cameras, radar and lidar and compute, that enable the ADS to understand the traffic scene around the vehicle.
- The motion planning system is a sophisticated set of software and hardware that combines the perception information and with route objectives to determine potential vehicle trajectories through a traffic scene.
- The control system then follows the desired trajectory by directing the powertrain, braking and steering systems to guide the vehicle.

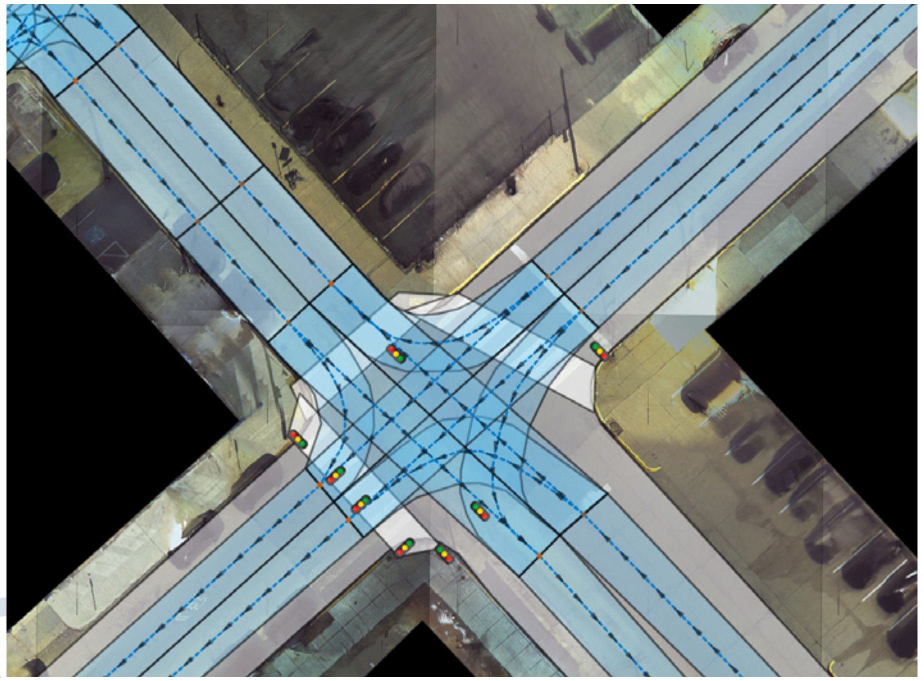
# HOW OUR SELF-DRIVING VEHICLES WORK (cont.)

## MAPS

One fundamental element of our self-driving vehicles is the detailed high-definition map of the roads on which they will be operating. The ADS uses maps to aid localization, perception, prediction, and motion planning decisions.

The maps contain detailed information beyond just roads and turns — they also contain detailed 3D information of the entire environment built for Ford's self-driving vehicles.

In fact, the map imagery is created by the self-driving vehicle's sensors as the test specialists manually drive our test vehicles throughout a city. During these initial drives, sensors built-in to the vehicle scan the roads, sidewalks and buildings, allowing for the creation of a 3D map. The base map is annotated with all the relevant traffic regulations and guidance, including road edges, directions of travel, speed limits, traffic signals, stop signs, crosswalks and yielding relationships. This map forms the basis of a complex system of perception and tracking, so the onboard computing system can use it to understand the static world before it even starts driving autonomously.



## PERCEPTION

Just like human drivers, the ADS needs information to operate. The ADS takes sensor data from the cameras, lidar and radar to infer what is happening in the world around the vehicle. The system observes other road actors, such as vehicles, pedestrians and bicyclists, noticing how they move and what their likely intended actions are. The ADS also detects road debris that the vehicle must avoid and, of course, detects the state of traffic lights relevant to the vehicle motion. Achieving human-level perception is a tremendous challenge and requires bringing state-of-the-art machine learning techniques to bear on the problem. The ADS combines information from all sensor sources in a carefully designed and thoroughly tested architecture that provides redundant sensing 360º around the vehicle. Redundancy is essential because different sensors have different failure modes.

## MOTION PLANNING AND CONTROL

At the core of self-driving is decision making. In order to drive, the ADS needs to continually receive information from the perception system, evaluate and select from a range of driving actions and execute those precisely to enable it to drive efficiently and safely. The vehicle takes actions that allow it to drive in a contextually safe manner that is predictable to other road users.

To do this, the vehicle continually evaluates different maneuver possibilities. Would it be better to slow down and follow a slow-moving vehicle or change lanes? The best decision depends upon a range of factors including traffic laws, the predicted motion of other road users and the vehicle's own driving route. Changing into a faster moving left lane only makes sense, for instance, if the vehicle is not planning to make a right turn a short distance ahead.

When planning any maneuver, the ADS plans to keep a safety envelope around the vehicle at all times. This envelope describes a safe following distance behind other road users and a lateral margin that gives other road users appropriate space as the vehicle drives by. In the final stage of the motion planning and control system, the ADS determines appropriate steering, brake and acceleration commands so that the vehicle executes the desired maneuver as designed and enforces the safety envelope.

## REMOTE ASSISTANCE

Argo AI has established Remote Guidance capability to provide human support to the ADS in the event there is a unique and challenging situation which requires additional guidance – for example, an unexpected road closure. Using cellular connectivity, the operator will assess the event and deliver information to the self-driving vehicle. As this is not the operator controlling the vehicle remotely, the ADS still executes the driving task based on guidance from the human operator when it is safe to do so.

# SAFETY
# RELIABILITY
# VALUABLE EXPERIENCE


As we develop our self-driving service, we are focused on three ideals that we believe are crucial to earning trust: safety, reliability and valuable experiences.

Ford is committed to the promotion of the safe implementation of self-driving vehicles not only in the U.S., but around the world. We are steadfast in cooperating with others who share our belief in ensuring the safe operation of self-driving vehicles. To this end, we have joined various consortiums, including the following:

**AVSC** – Ford is a founding member of the Autonomous Vehicle Safety Consortium (AVSC), convened by the SAE International and SAE Industry Technologies Consortia (SAE ITC). This consortium is working together to advance safer testing, development, and deployment of AVs through the establishment of industry best practices.

**PEGASUS[2]** – Along with other AV developers, Ford has joined PEGASUS, in the effort to identify areas for international collaboration and harmonization on safety assurance for ADS, and initiate steps to make progress towards collaboration and harmonization.

**AMP** – Ford has joined with other AV developers in the U.S., to form the Automated Mobility Partnership (AMP), which is geared towards the use of real-world driving data to inform the development of ADS systems.

Ford continues to play a leadership role in the development of various industry automotive standards, including:

**ISO[3] 26262** – Road vehicles – Functional safety

**ISO/PAS[4] 21448** – Road vehicles – Safety of the intended functionality

**ISO/SAE[5] 21434** – Road vehicles – Cybersecurity Engineering

Safety is a top priority in developing the processes we use for designing, testing and manufacturing our vehicles. We believe that the safety processes we have developed and demonstrated throughout Ford's history are key to earning trust. We're applying those time-tested processes to the development of self-driving vehicles, and we've created additional, new safety processes for self-driving technology. We are also designing for reliability through durability testing, using our extensive experience in building dependable vehicles that operate day after day, in hot or cold weather, and under a variety of road conditions.

**Our end goal, as our self-driving service comes together, is to create an experience that people enjoy, find valuable and trust.**

[2] PEGASUS: Project for the Establishment of Generally Accepted quality criteria, tools and methods as well as Scenarios and Situations for the release of highly-automated driving functions
[3] ISO: International Organization for Standardization
[4] PAS: Publicly Available Specification
[5] SAE: SAE International, previously the Society of Automotive Engineers

# APPLYING SAFETY PROCESSES

While the field of self-driving vehicle development may only be a decade old, Ford brings more than a century of experience in vehicle safety processes to the table. In partnership with Argo AI, Ford is integrating decades of vehicle safety experience with the latest advancements in industry best practices around the integration of vehicle hardware and software that enable autonomy into a safe, efficient and enjoyable experience for our customers.

## TEST SPECIALIST TRAINING

Throughout the development period, safety operators, or test specialists, are utilized in our test vehicles until the ADS meets the necessary performance and safety milestones to operate without them. We currently have two-person teams – a driver in the left-seat and a co-driver in the right-seat – in all our test vehicles. Also, before anyone is put in the driver or passenger seat of our test vehicles, they go through rigorous training and certification. The goal of the training, defined with our partner Argo AI, is to develop a standard professional framework for test specialists through a program that improves manual-driving skills in the classroom and then verifies those skills driving on closed courses. Test specialist training also provides education on self-driving technology. The training program is designed to be difficult and requires candidates to pass tests to advance through each phase.

Our test vehicles make it easy for test specialists to override the ADS in any situation. If the test specialist controls the vehicle in any way, by steering, throttle or braking, the vehicle returns full control with notification to the driver. The test specialist can also disconnect the ADS or disable the powertrain completely by pressing a fail-safe button in the center console. Once the test specialists complete training, they continue to work in teams of two with the test specialist in the left-hand seat focused on the road ahead and the test specialists in the right-hand seat monitoring the performance of the ADS via a laptop computer. Furthermore, test specialists cannot use a cell phone unless the vehicle is in "Park."

We also subscribe to a philosophy of continuous education and learning. There are mandatory pre- and post-shift daily briefings to share information amongst the teams, and there are regular classroom sessions to educate about new software releases and capabilities. Test specialist training is a critical element of deploying our development vehicles, and this is a view also shared by the AVSC. We have helped establish the AVSC Best Practice for safety operator selection, training, and oversight procedures for automated vehicles under test.

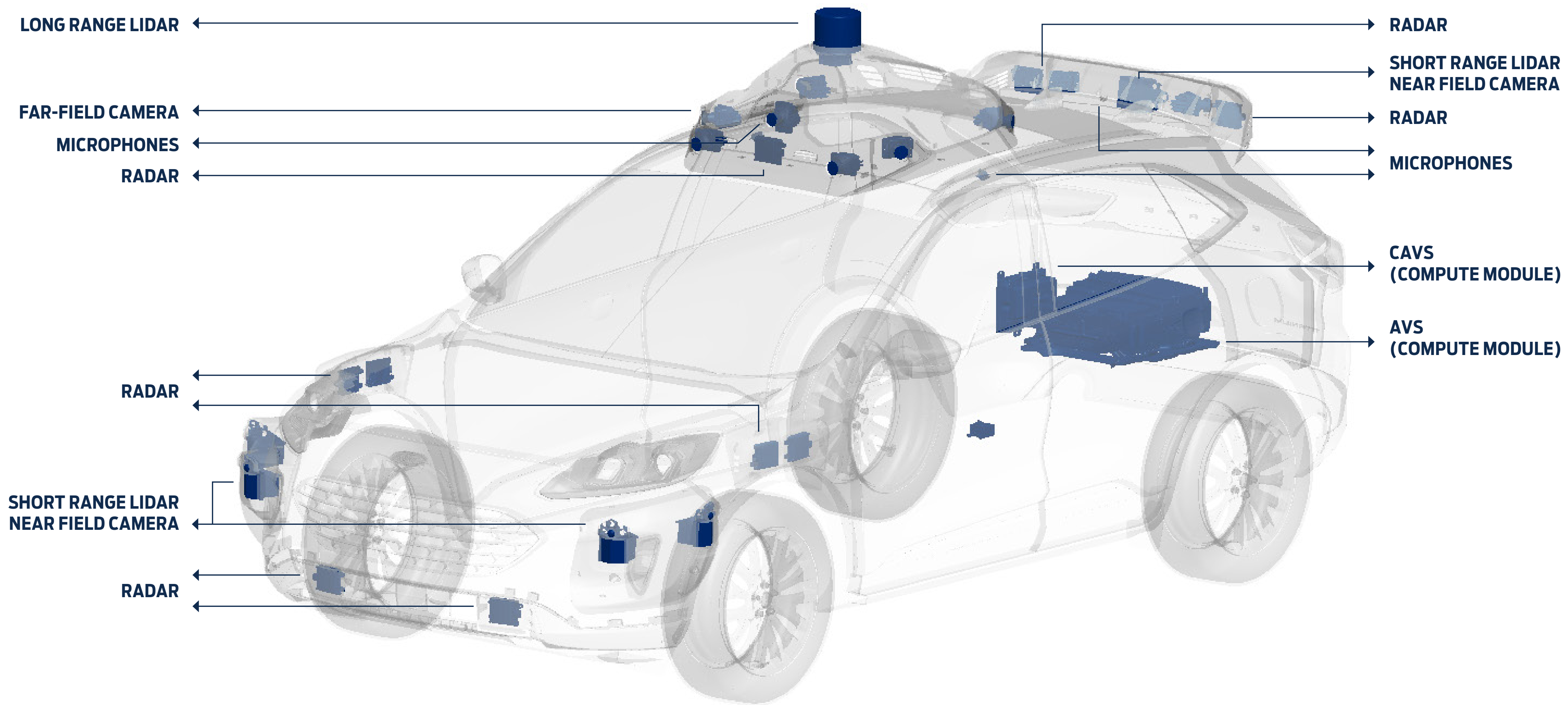
# DESIGNING FOR RELIABILITY

For self-driving vehicles to be embraced, the public needs to trust the technology. People tend to gain trust in something when they can predict what it will do. Part of earning the public's trust is for the self-driving vehicle to drive in ways that other motorists, cyclists and pedestrians expect; we call this "naturalistic driving." Each city has its own culture and expectations for how vehicles should drive. That's why we drive extensively in the actual cities where we will eventually deploy our self-driving vehicle fleet before we allow the vehicles to drive autonomously with the test specialists. In this way, we learn the roads, the challenging intersections and the local behaviors, so we can develop the system to operate as people expect. As a company, we're known for delivering dependable vehicles that meet and exceed customer expectations, in both private vehicle sales and fleet sales, like police, taxi and commercial trucking services. We are bringing that same focus on reliability to our self-driving vehicles.

To make our vehicles capable of self-driving, we redesigned and modified them to work with the ADS. We have added several new sensors and computing systems to understand the traffic and environment around the vehicle and make decisions for what to do next. We call this group of components and software the ADS. We also modified the traditional components to allow the ADS to control the vehicle with its computer-generated commands and capably handle system faults. We call this adapted set of traditional components the Autonomous Vehicle Platform, and it's designed to be applied to a broad range of different vehicles types.

## AUTONOMOUS VEHICLE PLATFORM

Contrary to what some might think, building an autonomous car isn't as easy as putting sensors and a computer into an existing car. The vehicle's traditional components and associated software must be developed and engineered to work together with the self-driving hardware and software to deliver a great experience. The end result needs to be a high-quality, energy-efficient vehicle people trust to serve their needs — just as they trust Ford vehicles today. Here's one of the challenges we face: in today's cars, if the rare event of a power failure, the driver is still able to mechanically push the brake pedal and steer to bring the vehicle to a controlled stop. Many of our self-driving vehicle systems have redundancies and are designed to be fail-functional. For instance, we have multiple power systems to ensure the ADS and platform receive power. If there is a loss of operation in one system, the ADS can still bring the vehicle to a controlled stop.




SOURCE: ARGO AI

# OUR NEXT-GEN TEST VEHICLE

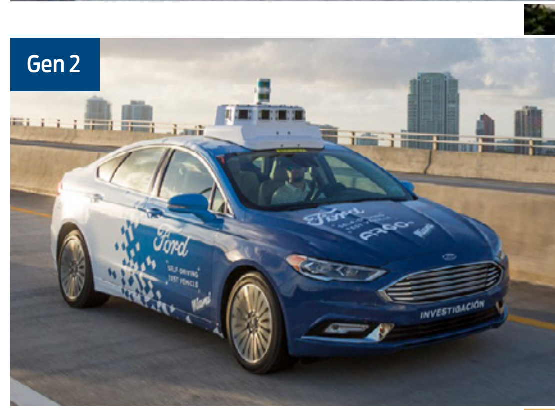
## *Laying the Foundation for Our Self-Driving Business*

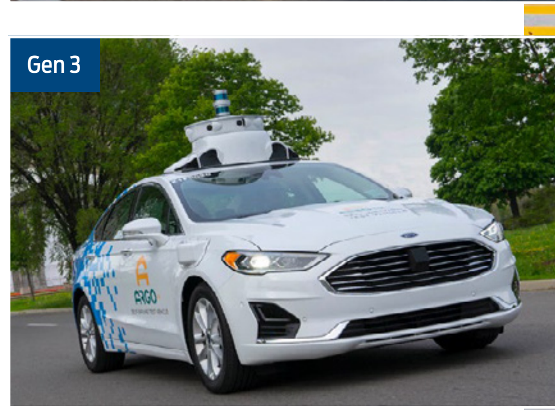
Ford and Argo AI have been operating and testing with our Fusion Hybrid self-driving test vehicles. In 2020, Ford and Argo AI revealed its newest self-driving test vehicle, built on the Escape Hybrid platform. The latest test vehicle features state-of-the-art sensing and computing technology. The Escape Hybrid is also the architecture and platform Ford has chosen to bring its autonomous vehicle service online.

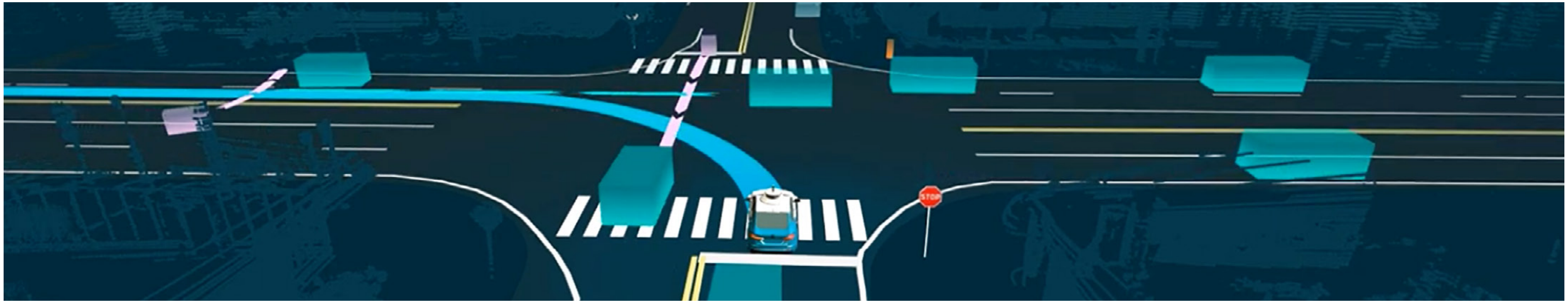
The systems we're incorporating into our newest test vehicles are "launch-intent" in terms of the components we believe will be needed to support commercialization. What this means is that with a well-defined architecture and platform in the Escape Hybrid, our team can continuously test and refine performance to better prepare us for launch. Everything we learn while using them can be channeled directly into our self-driving service as soon as it starts serving customers.

We are integrating these fourth-generation vehicles into our multi-city testing efforts alongside our Fusion Hybrids in Austin, Detroit, Miami, Palo Alto, Pittsburgh and Washington, DC.

We have said it before, but the vehicle is just one part of bringing together the future of self-driving services. With our fourth-generation test vehicle, we have everything we need from a vehicle to stand up our self-driving service.

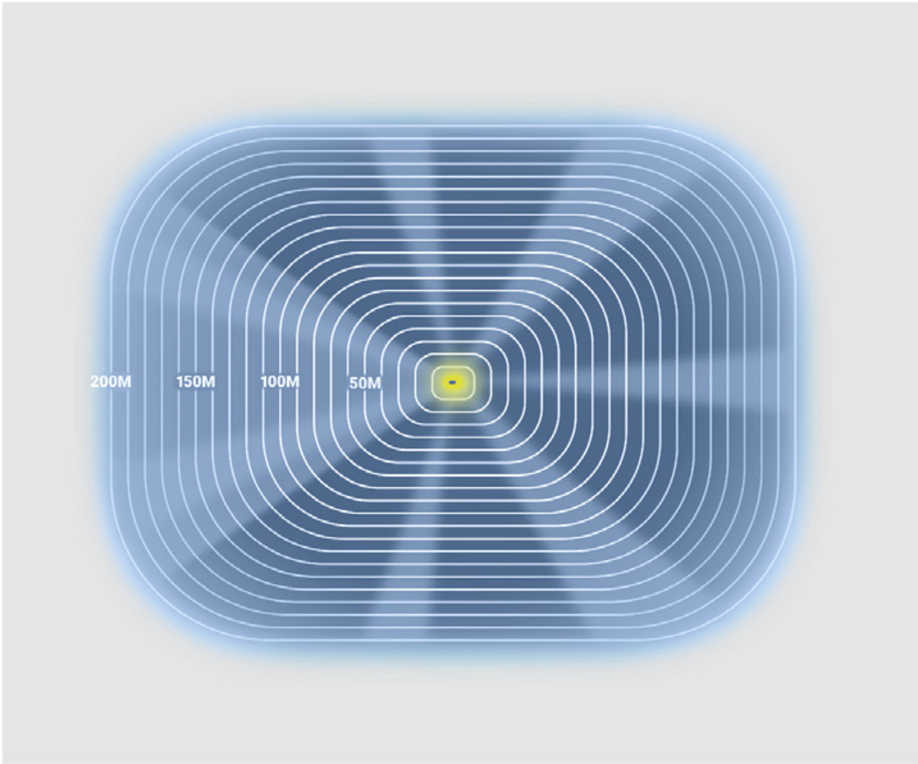



# SENSING THE ROAD AHEAD... AND ALL AROUND

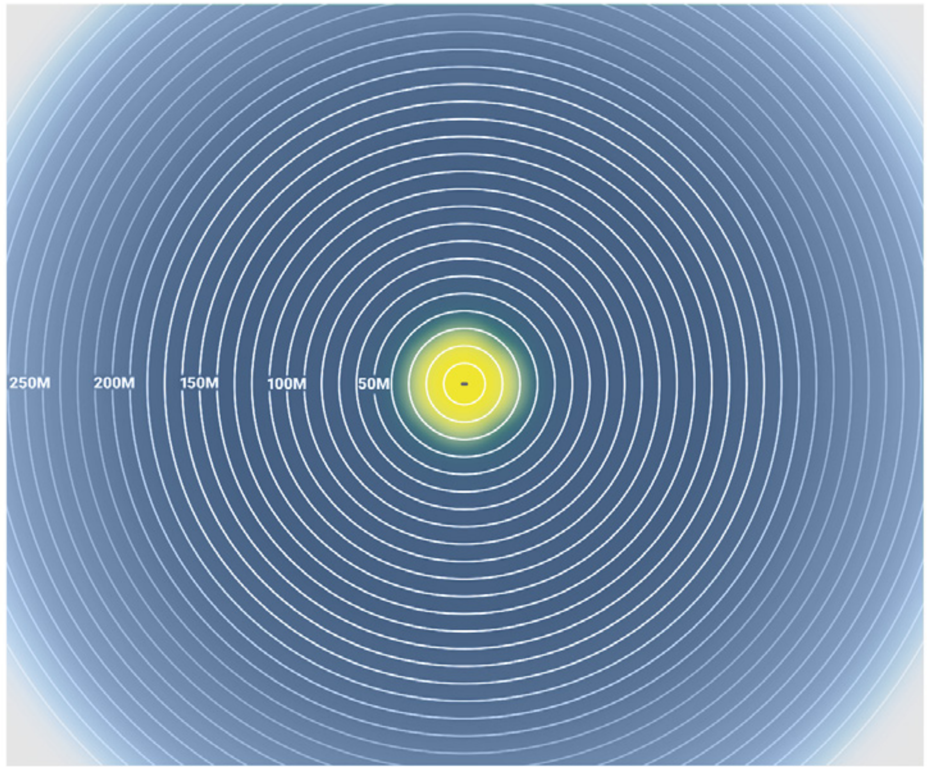
Ford's self-driving vehicles incorporate multimodal sensing that provides a 360-degree view of monitoring the environment in which they operate. It incorporates lidar, camera and radar providing overlapping perception capability, ensuring that at least two sensor types are monitoring at a minimum of 200m range – with some sensors exceeding 400m, which is more than three football fields in length. This means more than one type of sensor is observing the same area, and each detecting it a different way. The radar helps identify objects and the rate of speed of other vehicles. The cameras generate an image that can help the ADS recognize, classify and track objects including pedestrians and bicyclists.

⟵ Vehicle Direction



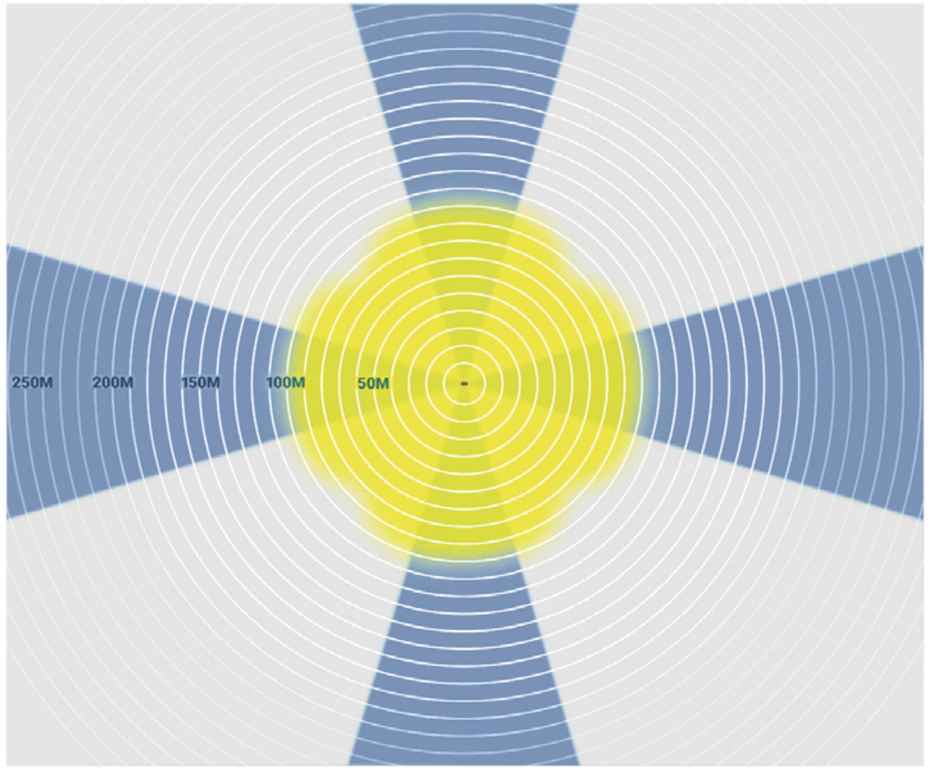

**CAMERA COVERAGE - GROUND PLANE**

- Near Field Cameras
- Far Field Cameras
- Vehicle




**LIDAR COVERAGE - GROUND PLANE**

- Short Range
- Mid Range & Long Range
- Vehicle




**RADAR**

- Mid Range
- Long Range
- Vehicle

SOURCE: ARGO AI

# KEEPING OUR SENSING SYSTEMS CLEAN

***Keeping our sensors clean from rain, dirt, debris and even insects is very important to ensure our vehicles can better "see" the world around them in a variety of challenging conditions.***

We are constantly researching and improving upon our systems to ensure they are safe, capable and precise. Think about all of the dust, dirt, grime and bird droppings that accumulates on your windshield while driving. The same thing happens on our self-driving vehicles on the "tiara," the structure that sits on top of all our self-driving vehicles and holds the collection of cameras, lidar and radar that helps the car "see" where it's going. It is important that the tiara is always clean so that it provides the best picture of the world while driving. As a result, we wanted to create a cleaning system that could be fully integrated into the self-driving vehicle's tiara.

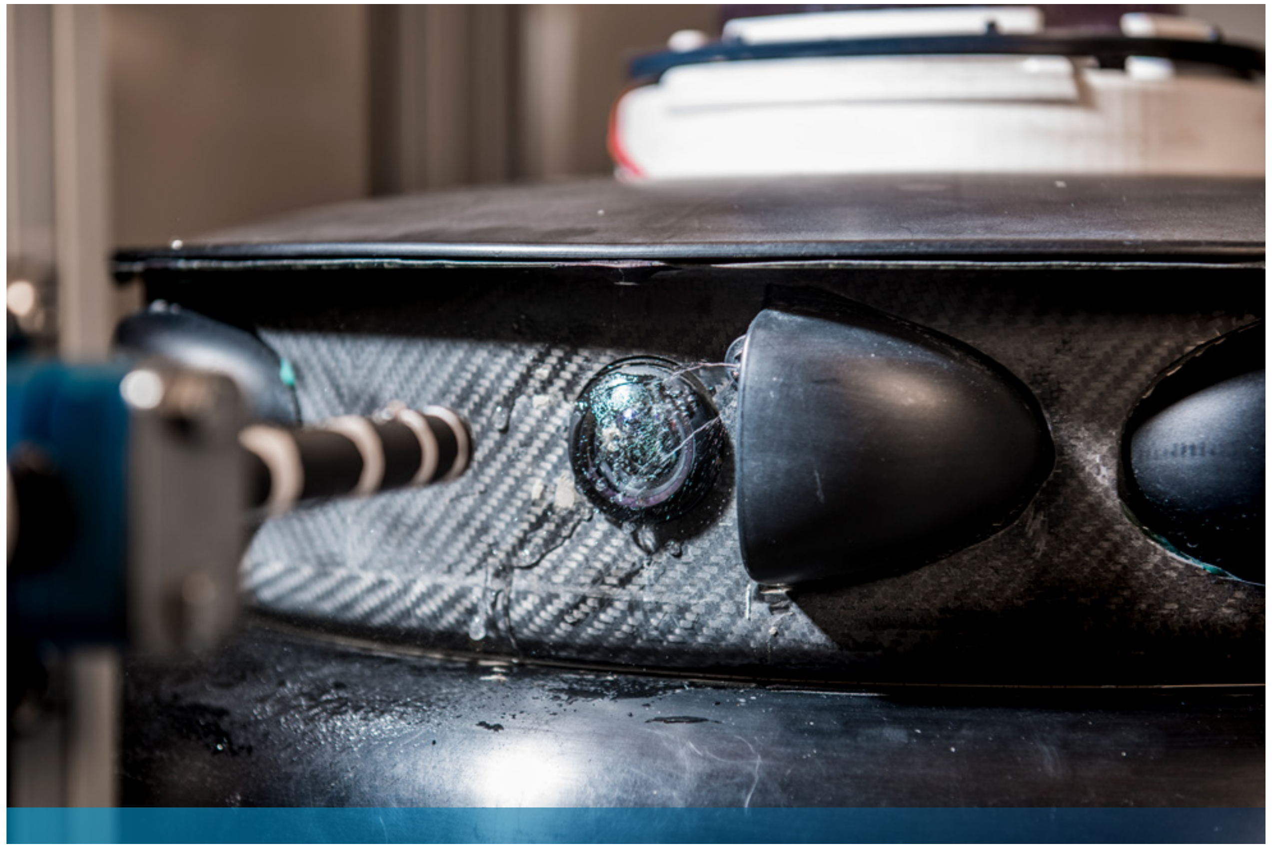
The initial cleaning system we developed for our third-generation self-driving vehicle test fleet feature next generation nozzles next to each camera lens that can spray washer fluid as needed to clean the sensors. The cleaning system uses advanced software algorithms that help our self-driving vehicles determine when a sensor is dirty and it can specifically hone in on one or multiple dirty sensor lenses to efficiently clean each one. After a sensor has been sprayed down, our tiara has an innovative way of drying the sensor lenses. It releases air through an air nozzle which quickly "dries" the face of the lens.

We initially tested the cleaning system using the bug launcher, a tool our team of engineers at Ford created to test and understand how we can best clean insects off. The bug launcher uses compressed air to propel the bugs onto the sensors.

The cleaning system was equipped on our third-generation self-driving test vehicles in Detroit, Austin, Pittsburgh, Miami-Dade County and Washington DC to test in a variety of environments. As a result of the real-world testing, we have refined the cleaning system for our fourth-generation self-driving test vehicle. Some of the key new enhancements include:

- Hidden, forced-air cleaning chambers that surround the camera lenses and LiDAR sensors to ensure their field of view is clear while providing 360-degree cleaning coverage
- Increased the number of spray nozzles and coverage areas for improved liquid cleaning; and
- Increased pressure to aid cleaning speed.

Additionally, we've extended these new cleaning designs to our added near-field cameras and lidar sensors as well. With these enhancements and improved hydrophobic coatings, our latest test vehicles are much better equipped.

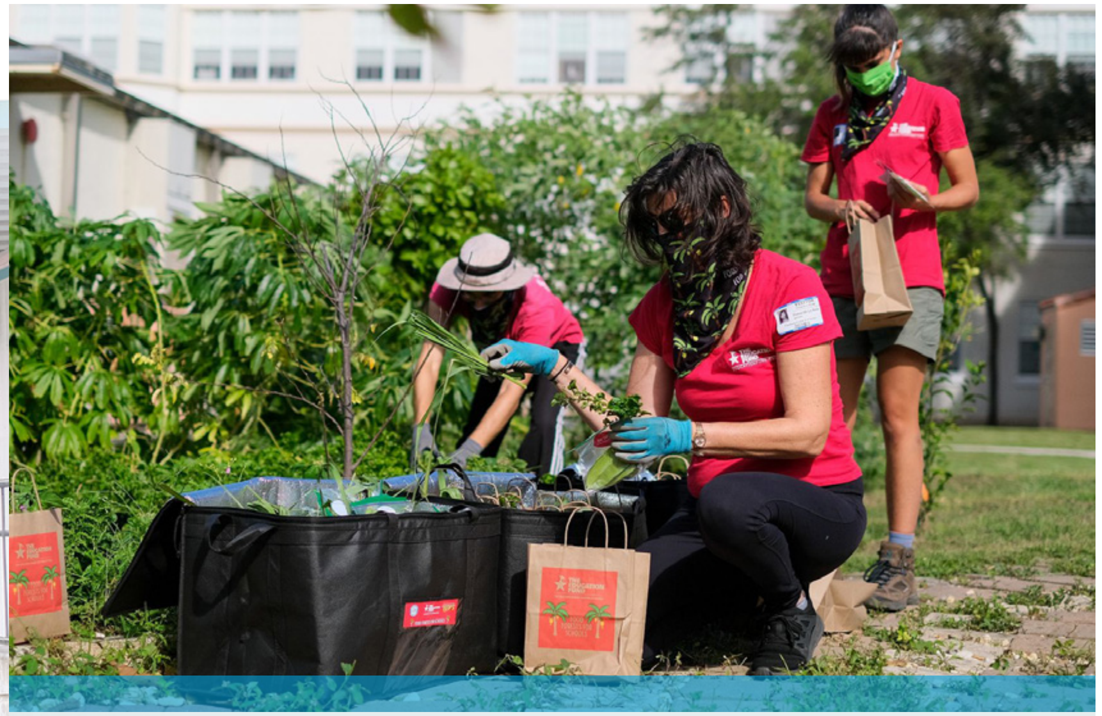


# OUR SERVICE: RIDE HAILING AND DELIVERY

**FORD** believes self-driving vehicles have the potential to make a positive impact in our communities by providing greater access to transportation and delivery services.

Collaboration is at the center of our approach as we build our business in each of our launch markets. We are committed to working closely with local officials and the community to understand how our service offerings can integrate within the existing transportation system and how they can provide value. To do this, we are continuing to conduct pilots that will help us stand up our self-driving business to move people and goods.

For example, in Miami we wanted to build upon our past pilots and also find a way to help the community as it deals with the challenges of the global pandemic. As part of this, we teamed up with a local non-profit to deliver fresh produce and school supplies to local Miamians. This was the first time we integrated the self-driving capabilities from Argo AI with our customer-facing partnerships. As a result, this provided us meaningful real-world insights into what is required to run an efficient business.

Ford recently teamed up with The Education Fund, a local non-profit in Miami-Dade County, building on previous business pilots to now conduct deliveries with our self-driving vehicles in autonomous mode.

# CUSTOMER EXPERIENCE: THE CORE OF OUR SERVICE

Self-driving technology has tremendous potential to change people's lives and the communities in which they will operate. In addition to developing the technology in a safe and reliable manner, we are making sure it is being applied in ways that will deliver experiences that are valued.

As we design the ride-hailing and goods delivery services that self-driving technology will enable, we strive to put people at the center of our thinking. We want to ensure that self-driving technology works to enhance people's lives.

Our customer experience will be our differentiator and is at the core of our service. We are building a great experience that offers our customers the peace of mind of knowing they, or their packages, are safe and in a protected environment.

The foundation of this experience will be a Transportation-as-a-Service (TaaS) software platform, powered by the cloud, that can integrate seamlessly with other businesses, dispatch vehicles and orchestrate the fleet. We must provide our riders and goods-delivery customers transparency, with access to key info including ETA, route flexibility and control. To do this, we're beginning to design and test customer experiences in parallel with our efforts to develop the technology.

# OUR COLLABORATION WITH CITIES

Every city has unique transportation needs and **FORD** understands you can't just copy and paste a service from one city to another.

By working closely and collaboratively with city officials, community leaders and local businesses, we will build and deploy a self-driving service that is part of the city's transportation ecosystem.

In addition, Ford will invest in the local community through real estate development, job creation and provide a mobility service that has the potential to reduce congestion and accidents. Before a single one of our test vehicles starts driving autonomously in a city, Ford, Argo AI and the city work together to identify where self-driving cars could make the biggest difference, considering a number of factors, including where the demand is, what the market wants, and how we can meaningfully contribute to the transportation network already in the city.

For example, we are testing smart infrastructure technology using Ford-designed smart nodes in Miami to research complex intersections and scenarios our self-driving vehicles may encounter. The node is equipped with sensors like radar, lidar and cameras and situated above the intersection, so it can offer a bird's-eye view of the area to support a self-driving vehicle as it analyzes its surroundings at a street level. While it is not required for a Level 4 self-driving vehicle to operate safely, this sensor node can quickly relay even more information to a self-driving vehicle, providing an additional layer of information about the situation it's about to encounter long before it approaches the intersection. We worked closely with Miami-Dade County, the City of Miami Beach and the Florida Department of Transportation to make this possible, and they have been key collaborators.

Ford's smart node installed just below the street sign on the right at a complex intersection in Miami's South Beach.

Austin Assistant City Manager Gina Fiandaca speaks at press conference announcing plans for Ford's self-driving service launch in Austin, Texas.

# RESEARCHING A SELF-DRIVING LANGUAGE

Today, pedestrians and bicyclists can look into a car and make eye contact with the driver to assure themselves that they are seen. A driver usually nods their head or waves a hand to indicate it's okay to cross the road. But, what about in a driverless future?

We believe a standard way for self-driving vehicles to easily communicate their intention to people on the streets where they will operate could help communities trust and interact with the technology.

As a result, we set out to develop a common language that self-driving vehicles can share with other road users. To communicate with people outside the vehicle, we designed a light bar to be placed in an area where a pedestrian or cyclist may look for cues from a human driver. We continue to investigate what light bar signals are most effective, such as the full light bar being in a steady on state when the vehicle is accelerating or driving at speed.

Communicating effectively with limited assumptions on common language, or symbology, is very challenging. There are thousands of languages throughout the world, and many countries have more than one official language, which makes it nearly impossible to ensure text-based signals can effectively communicate with the greatest number of people.

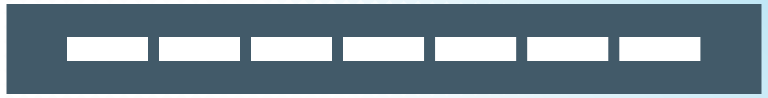
Additionally, human-driven vehicles typically communicate what they are doing – not what others, such as pedestrians, should do. Red brake lights indicate a vehicle is slowing or stopped. A turn signal indicates it is turning right or left. So, it's important to build off the current applications of light communications on vehicles today. Also, many regulators around the world restrict what colors can be used for lighting on the front of a vehicle, so white or amber is the best option.

To test out the signal patterns in the real world, we worked with the Virginia Tech Transportation Institute to create a "simulated" autonomous vehicle. Through our testing, which encompasses more than 180 hours and 2,300 miles in a dense urban area, we have results that suggest there may be a societal benefit to creating a standardized communications method.

Our light signals still need to undergo additional research, but we believe development and adoption of a global standard is critical to support the deployment of self-driving vehicles. Ford is leading an International Organization for Standardization (ISO) initiative to develop the ergonomic design guidance for external visual communication from self-driving vehicles to other road users.

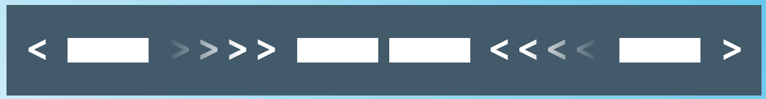
## Possible Light Bar Signals Ford Is Researching

### Driving Autonomously



LIGHT BAR FULLY LIT

### Actively Braking/Stopped

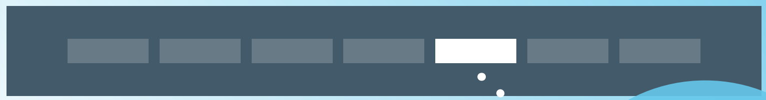


LIGHT BARS MOVE FROM EDGES TO CENTER

### Active Pick-Up/Drop-Off Underway

LIGHT BAR COUNTS DOWN FROM EDGE TO CENTER

### Recognizes Road Uses



LIGHT BAR TRACKS AND FOLLOWS ROAD USER POSITION

## Ford's Research With Virginia Tech Transportation Institute

# SAFETY ELEMENTS

Safety is our first concern at every step in the development of our self-driving vehicles. In this section, we will address the twelve safety elements in the National Highway Traffic Safety Administration's policy guidance, *Automated Driving Systems 2.0: A Vision for Safety*.

# SYSTEM SAFETY

**System Safety refers to the holistic strategy that helps minimize failures and prevent unreasonable safety risks throughout the design, validation and testing processes.**

Safety doesn't mean a sensor will never fail or software will never encounter issues.

***Our goal is to design a robust ADS that is able to mitigate these errors and bring the vehicle to an appropriate Minimal Risk Condition (MRC) when issues arise. It's about a holistic strategy to reduce the risk of failures and help protect people in case something does go wrong.***

At Ford, we place safety at the heart of the process and build the entire system — vehicle, software, testing and training — around it. System Safety drives our entire development approach, helping ensure safety even in the unlikely event a component fails or the vehicle suffers a problem — how, when and where our vehicles operate.

At every stage of design and testing, Ford's engineers use systems engineering tools and processes and supplement them with lessons learned in the field and industry best practices. Our functional safety process is strongly aligned with the industry automotive safety standard (ISO 26262). Ford was engaged at the early stages of the original ISO 26262 standard development and was selected to lead the United States Technical Advisory Group (USTAG) for the development of the Safety of the Intended Function (SOTIF) ISO standard. For the autonomous vehicle application, we also integrated and applied hazard analysis techniques, such as Systems-Theoretic Process Analysis (STPA), along with aspects of the SOTIF draft Standard, ISO 21448.[6]

[6]The ISO/PAS 21448 Road vehicles - Safety of the intended functionality publicly available specification (PAS) was released in the beginning of 2019. The full standard version is in process and expected to be released in 2022.

From this process, we generate safety requirements for the vehicle's Operational Design Domain (ODD) (*see page 28*), Object Event Detection and Response (OEDR) (*see page 29*) and fallback maneuvers that achieve an MRC (*see page 30*), along with associated safety verification and validation procedures. These requirements, in turn, guide the creation of a vehicle design that meets the goals defined at the outset. As testing reveals limitations of the current requirements, these lessons are fed back into the design process, becoming more robust over time. To this end, we are engaged with others in the industry in setting the foundations for best practices around safety assurance for an ADS.

This means designing systems for braking, steering, and power that can continue to function even when experiencing faults that would have previously required driver intervention. This requires designing for fallback scenarios to ensure a vehicle can reach an MRC. Our self-driving vehicle includes an in-depth diagnostics strategy to analyze faults and perform the appropriate type of fallback to bring the vehicle to a controlled stop when necessary.

Our engineers apply these standards to design self-driving vehicles capable of safely navigating the world. For example, we design software that knows when to change lanes, navigate intersections or handle the unexpected — and knows what failing safely means in these contexts. Our self-driving vehicles are governed by robust safety requirements, including a tightly defined ODD, that are developed through rigorous testing. In other words, we provide the vehicle with the programming required to respond appropriately

# SYSTEM SAFETY (cont.)

**System Safety refers to the holistic strategy that helps minimize failures and prevent unreasonable safety risks throughout the design, validation and testing processes.**

## SAFETY STRATEGY

How does Ford design safety into every self-driving vehicle? We have an established systems safety process integrated into our technology and product development processes. This promotes a systems approach for cross-functional collaboration to identify and develop a design that meets our safety requirements.

Test specialists are a crucial part of our development process, and our prototype vehicles are designed to ensure that a trained test specialist can intervene. We design the intervention capability in many different components, such as placing limits on the ADS, which is designed to cede control to the human driver rather than the computer.

***Backup systems in our production intent vehicles will provide fail functional operations in our self-driving vehicles. This means a secondary braking system will ensure the vehicle can come to a controlled stop even if the primary braking system fails. In addition, the steering system has the ability to maneuver if one of the steering systems fails. The self-driving control systems are designed so that they can bring the vehicle to a safe state in the event of a failure in the primary or secondary computing hardware.***

Since power is crucial to every critical system, our self-driving vehicle is also designed with independent power systems, which allow the vehicle to continue safe operation even after a single power failure or disturbance.

## TEST SPECIALIST TRAINING

At this stage in developing our self-driving vehicles, we believe test specialists play a critical role in the event of an error or malfunction. Their training is a core feature of our overall system safety.

Mirroring our validation and testing process of hardware and software, drivers proceed through three levels of instruction. First, they become familiar with the test vehicle and city through classroom and in-vehicle training. Second, they practice in a simulated urban environment at a closed-course facility, growing more comfortable with the vehicle's performance and ADS as well as the ODD.

***Test specialists are expected to remain constantly attentive to system performance as well as monitor other road users.***

They are specifically instructed and monitored to ensure they never consume media, or talk or text on their phones, and they are continually evaluated on their ability to apply corrective input in a wide variety of driving scenarios, including random fault injections.

In the training program's third and final phase, test specialists begin to run start-to-finish autonomous missions on public roads. Monthly spot checks of the test specialists help ensure high standards.

Even after training is complete, ongoing daily briefings keep test specialists up to speed on new features and they provide feedback on testing, which is vital for teaching our safety engineers how to refine their designs for the next batch of improvements.

# OPERATIONAL DESIGN DOMAIN

**Operational Design Domain (ODD) describes where, when and under what conditions our self-driving vehicles will be designed to operate.**

Most human drivers have a comfort zone. Some prefer to avoid highways and stick to local roads when possible; others would rather not drive at night or in bad conditions, such as during snow or ice storms. These driving routines and decisions can be considered a comfort zone.

The difference between most drivers and Ford's self-driving vehicles is that our comfort zone is set in code.

***Our ADS only works within its ODD, which prescribes which areas, streets, speeds, weather and time of day our vehicles can safely operate.***

As a part of our safety leadership efforts, Ford was involved in the development of the AVSC Best Practice for Describing an Operational Design Domain: Conceptual Framework and Lexicon, and utilizes the framework to establish the definition of our ODD. Emerging from the requirements generated by our System Safety processes, the ODD defines the vehicle's area of operation. As the capabilities of our vehicles improve, we expect the ODD will expand in size and scope over time.

For our initial launch, our self-driving vehicles are being designed to operate at typical speeds for urban streets (e.g. boulevards and collector roads) within strictly mapped geo-fenced areas. The vehicles will be equipped with technology designed to detect and respond to static external environments, such as road structures and features (e.g. curbs, lane markings and barriers), roadside objects (e.g. trees and debris), dynamic objects (e.g. cars, trucks, motorcycles and bicycles) as well as pedestrians, first responders and animals. Our vehicles will initially operate day and night under a variety of light conditions, as well as during light precipitation.

Our intended ODD represents a convergence of our vehicles' expected capabilities and our projected business model, which includes ride-hailing and goods delivery along urban streets. It's important to note that, while the ODD includes a geo-fenced boundary, its operations within it are constrained by its ability to operate safely. For example, our vehicles will be programmed to stay within the ODD. This may include in some circumstances avoiding highways, complex intersections and any other considerations exceeding its ODD.

In the event driving conditions sufficiently change to violate the ODD's conditions, our vehicles will implement a fallback maneuver to achieve an MRC.

# OBJECT AND EVENT DETECTION AND RESPONSE

**Object and Event Detection and Response (OEDR) describes the capacity of the self-driving vehicle to detect and respond to environmental stimuli, both on and off the road.**

Driving is a feedback loop of identification, prediction, decision making and execution. Once behind the wheel, we find ourselves constantly asking questions. What is our speed? Is it too fast? Is that car changing lanes? Is that person waiting to cross the street? Is there an obstacle in the road? In each case, we decide whether and how to take action: to speed up, slow down, signal, stop or evade. Human drivers make decisions through a combination of intuition and experience. Our self-driving vehicles do much the same using sensors, software and onboard computing systems.

These capabilities comprise the vehicle's OEDR system, which is responsible for perceiving conditions around the vehicle, taking a path, recognizing objects and other road users, predicting their behavior and responding accordingly.

Our vehicle's OEDR is designed to be a match for environments prescribed by the ODD. When driving conditions exceed its abilities, or the vehicle encounters a problem for which it has no response, it defaults to perform a fallback maneuver to achieve a Minimal Risk Condition. To achieve this, Ford's self-driving vehicles employ a diverse set of sensors, combined with dynamically updated maps of the ODD.

***Our validation and testing includes an iterative process of simulation, closed-course testing and real-world testing to refine the OEDR system's capabilities and validate results from previous steps. There's no substitute for real-world driving experience. The ADS learns this just as any human driver does.***

# FALLBACK (MINIMAL RISK CONDITION)

**The response by the ADS to perform the Dynamic Driving Task (DDT) or achieve a Minimal Risk Condition (MRC) after the occurrence of a DDT performance-relevant system failure or upon Operational Design Domain (ODD) exit**

When things go wrong, decision-making for human drivers is not always easy or clear. But for our self-driving vehicles, the next steps are written clearly in their code.

***Our vehicles rely on a comprehensive, robust diagnostics strategy to identify fault conditions. Vehicle components conduct their own onboard diagnostics (no internet required) and critical subsystems such as the ADS, and the braking and steering systems have redundancies.***

In the event of a fault that affects the driving ability of the Autonomous Vehicle Platform or critical capabilities of the ADS, Ford's self-driving vehicles will perform a fallback maneuver to reach an MRC. Whenever possible, the vehicles will pull over outside of traffic. Just as a human driver may make the decision that the best available option is to stop immediately, more serious conditions may require Ford's self-driving vehicle to stop in lane. Fail-functional power systems, communications networks, controllers and actuators ensure continued ability to execute fallback maneuvers in the presence of faults. We build on Ford's decades of engineering best practices to conduct extensive testing to reduce the occurrence of faults that would require the vehicle to perform a fallback maneuver.

As part of its leadership on safety, Ford worked with its industry partners in the Crash Avoidance Metrics Partnership (CAMP) to develop and communicate an industry position on MRC conditions requiring vehicle stops.

If a trip is interrupted due to a fault, on-board communications will provide information for any riders. We will facilitate transfer of any riders or goods to another vehicle to complete the trip. Ford's mobile response team will be activated to retrieve and/or repair the vehicle as soon as possible.

While connectivity isn't essential for vehicle health monitoring, our self-driving vehicles will transmit diagnostics information to the cloud platform for better customer service and to facilitate scheduling of service and maintenance.

# CYBERSECURITY

**Cybersecurity is designed to protect the self-driving vehicle and the riders within from unauthorized access.**

Cybersecurity is an important part of the world in which we live. Ensuring the integrity as well as the safety of our self-driving vehicles is a top priority. Self-driving vehicles present a unique challenge in terms of cybersecurity, combining unprecedented sophistication in a vehicle with frequent software updates and cloud-controlled features.

Ford builds security in the heart of our System Safety process. Our cybersecurity strategy extends not only to the vehicles' electronics, sensors and ADS but also to any feature connected to them, such as data ports, mobile apps and customer service systems.

***We employ the industry-standard defense in-depth approach of layering security across multiple overlapping systems working together. Our system is designed to reduce the possibility of entry into a vehicle's network by using component isolation techniques, memory protection and access controls on any embedded systems, especially with external interfaces or safety functions.***

Our system also reduces the ability of a compromised device to affect behavior through message authentication, verification and credential provisioning. Additionally, our system minimizes the impact of any breaches via network segregation and physical and virtual partitioning, among other measures. Our validation techniques help ensure no single corrupted component jeopardizes the health of the overall system.

Not content to assume the security of our own solutions, our cybersecurity team works with partners and suppliers to help ensure our self-driving ecosystem and supply chain are also secure. Regular engineering testing, red team exercises and monitoring of the vehicle help to ensure an adequately tested system. Regular engineering security testing, penetration testing, and monitoring  are commonly performed to help ensure an adequately tested system. Outside security assessments are conducted at various points to help ensure that security issues are found and resolved.

Due to the ever-changing nature of the cybersecurity landscape, current design features are rigorously tested against our library of threats and attacks. This library is constantly updated. cross-referencing Common Vulnerability and Exposure (CVE) alerts from the National Institute of Standards and Technology (NIST) and other threat sources. Ford is a founding member of the Auto-ISAC and chaired the important SAE/ISO 41434 standard. Ford efforts are aligned with best practices including ISO 21434, UNECE WP.29, and the NHTSA Cybersecurity Best Practices for the Modern Vehicle.

# DATA RECORDING

**Data from self-driving vehicles feed powerful analytical tools that can be used to maximize the safety potential of self-driving vehicles.**

Learning to drive requires practice, experience and memory. Every driver carries an expectation of how their vehicle and others should behave on the road. We rely on experience to vet these hunches and know what to do in unique situations, but for that our self-driving vehicles need data.

Our development teams record terabytes daily from simulations and test vehicles with the latter providing performance data from onboard systems such as braking, acceleration, and steering, in addition to sensor and camera data from the ADS. The ability to recreate actual events in simulations helps us to refine our approach and build better systems.

As we approach deployment of our self-driving services, our recording practices will increasingly shift from continuous to event-driven. In practice, this means events rising to a predetermined threshold will automatically trigger data recording. In addition to collisions and events requiring significant evasive maneuvers, this list will also include any fault requiring a fallback into an MRC, disengagement by the ADS, cyberattacks, and may also include rider-initiated events and customer service interactions.

***Our self-driving vehicles will use conventional Event Data Recorders (EDRs) compliant with the regulatory standards for data recording during crash events. In addition, an autonomous vehicle data storage device will log information from onboard systems and the ADS.***

Onboard storage will be capable of storing data-rich events that can be read during scheduled maintenance.

In support of these efforts, we have helped develop the AVSC Best Practice for Data Collection for Automated Driving System Dedicated Vehicles to Support Event Analysis, which recommends the uniform collection, storage, and retrievability of onboard AV event data. We are also working with the Virginia Tech Transportation Institute (through the Automated Mobility Partnership), which grants us access to several million miles of naturalistic data from edge cases and impact events that informs our ADS development.

# CRASHWORTHINESS

**Crashworthiness refers to the ability of the self-driving vehicle to protect its occupants in the event of an accident or crash.**

For more than a century, Ford has been a pioneer in the crashworthiness, biomechanics, and occupant protection field. Ford's expertise has led to the development and implementation of several crash protection features and technologies that were industry firsts, including:

- **1927:** Ford was the first to have standard laminated windshields which helped contain occupants in the event of a frontal crash.
- **1955:** Ford was the first automaker to offer factory installed safety belts.
- **1989:** The Lincoln Continental was the first domestic vehicle to have standard driver and passenger airbags. Less than 10 years later, depowered airbags were offered across the Ford fleet due to Ford's research of real-world accident data and injury trends. This analysis also influenced regulation changes and drove the effort to depower frontal airbags to enhance the safety of small stature and Out-Of-Position occupants from injuries and fatalities caused by airbag aggressivity.
- **2000:** The 2000MY Ford Excursion, followed by the F-250 and F-350, was equipped with a blocker beam which was designed to reduce or inhibit potential over-ride in collisions between SUVs/trucks and passenger cars by lowering the point of impact, thereby providing better compatibility with smaller vehicles.
- **2002:** Ford offered the Safety Canopy system, consisting of a side curtain and an industry leading rollover sensor, in the 2002MY Explorer.
- **2003:** The knowledge behind the blocker beam was one of the main drivers of the geometrical compatibility voluntary standard issued by the Alliance of Automobile Manufacturers[7] and Insurance Institute for Highway Safety (IIHS).
- **2003:** Ford was the first to patent a new Roll Stability Control system.
- **2009:** Ford introduced the first inflatable belt system, offering enhanced rear seat safety for elderly and child occupants compared to standard seat safety belts, available in the 2011MY Explorer.
- **2015:** The 2015MY F-150 was the first pickup truck with an aluminum cab that received a “Good” IIHS roof strength rating.
- **2021:** Ford's all new, all-electric SUV, the Mustang Mach-E, earned the Top Safety Pick (TSP) Award of the IIHS. It achieved Good ratings in all six crashworthiness tests that cover driver- and passenger-side small overlap frontal impact, moderate overlap front impact, side impact, roof strength and head restraints/seats.

***Ford is continuously developing the tools and methods used to assess and improve the crashworthiness of their vehicles, both independently and with industry partners.***

Ford has been and is involved with global efforts to develop and evaluate both physical and virtual Anthropomorphic Test Devices (ATDs) and their associated biomechanics criteria. In the early 1990s, Ford aided the development of CAE ATD models by providing performance data to the model developers. In the early 2000s, Ford was part of the global effort to develop the WorldSID-50M, a side impact mid-size male ATD with improved biofidelity over previous side impact ATDs. Ford developed a full human body model that includes highly detailed internal organs, especially the comprehensive human brain model that has been used to better understand the extent of injuries, especially tissue damage, that can occur during a crash. By contrast, ATDs measure the force of impact, but not potential injuries to internal organs. We are also developing a child-size human body model to better understand the impacts of crashes on young passengers. These tools may also help in the development of more human-like crash dummies, with more sophisticated instrumentation.

[7] In 2019, the Alliance merged with the Association of Global Automakers to form the advocacy group, the Alliance for Automotive Innovation.

# CRASHWORTHINESS (cont.)

**Crashworthiness refers to the ability of the self-driving vehicle to protect its occupants in the event of an accident or crash.**

Ford's crashworthiness, biomechanics and occupant protection expertise and contributions led to the development of a host of technologies, tools and safety test methods that have made significant contributions to automotive safety. We're leveraging our experience and our comprehensive, science-based system, which takes into account real-world accident data and societal trends, to develop and execute new safety-related technologies to ensure our self-driving vehicles can meet all applicable federal, state, and local regulations and make a difference in real-world safety.

***And, just as our stringent internal guidelines add stricter scrutiny to multiple types of crashes and pedestrian impacts, our production-intent self-driving vehicles will not only meet these same requirements, but new requirements may also be developed arising from unique situations from the addition of roof-mounted sensors and secondary braking, steering and power systems.***

Our crashworthiness process comprises computer-aided modeling, engineering assessments, component testing, subsystem / sled testing and full vehicle system evaluations. Our safety approach focuses on reducing the accelerations and loads occupants experience during a crash through the optimization of restraints (e.g. seatbelts and airbags) and structural elements such as bumpers, rails and pillars while maintaining the structural integrity and mitigating intrusion into the occupant compartment. For hybrid electric vehicles, including our development and production-intent self-driving vehicles, the battery's housing structure is designed to perform well and maintain battery integrity in a crash. Ford is also developing a methodology to optimize the placement of electrical system components in an electric vehicle to reduce risk in the case of a crash.

We are currently researching issues especially relevant to self-driving vehicles, including changes in kinematics from the distribution of sensors around the vehicle, guidelines for the new and nonconventional seating configurations, and storage racks for our ride-hailing and goods delivery businesses. Ford has worked with the University of Michigan Transportation Research Institute (UMTRI) to research how onboard sensor and diagnostic systems might be used to enhance passenger safety, such as airbag pre-deployment ahead of a detected collision. Along with UMTRI, we have also looked at how the introduction of self-driving vehicles may change the crash scenarios. With the Virginia Tech Transportation Institute, we have researched the risk of passenger injuries arising from deployable restraint systems developed for unique seating configurations. Additionally, we have been investigating the possible modifications to restraint systems that may be needed with these new and nonconventional seating configurations.

Our self-driving vehicle crashworthiness process will reevaluate the base vehicle's crashworthiness performance and validate all of these updates through simulation and testing. Because we safety test each vehicle independently, our crashworthiness tests will also validate that more standard elements like airbags and seatbelts meet Federal Motor Vehicle Safety Standards (FMVSS).

# POST CRASH BEHAVIOR

**After a crash, the self-driving vehicle will be brought to a stop to allow for investigation and rider assistance, as needed.**

Once a self-driving vehicle is deployed without test specialists in the vehicle, crash events will trigger the vehicle to execute a fallback maneuver and reach an MRC, coming to a safe stop. If necessary, backup steering, braking and power systems help ensure the vehicle is able to stop under its own power. Depending on the severity of the crash, as judged by the self-driving vehicle's crash detection algorithms, the following may happen:

- The self-driving vehicle will use its embedded modem to connect with a specially trained AV Customer Care (AVCC) representative who will then connect with the Public Safety Answering Point to notify first responders and communicate with individuals in and around the vehicle, if needed. The AVCC representative subsequently will check on the occupants' health and safety and to help communicate next steps.
- If necessary for safety or regulatory purposes, the high voltage battery will disconnect power for the safety of occupants and first responders while the 12V power supply enables hazard lights and doors to unlock.
- Data from the crash will be logged automatically, using its Event Data Recorders (EDR) and autonomous vehicle data recording device. Details such as airbag deployment, vehicle speed, seatbelt use, braking, acceleration, and steering, as well as ADS system and sensor data can help us understand what happened.
- If necessary, after verifying rider health and safety, the service representative will facilitate transfer of any riders or goods to a second self-driving vehicle to complete the trip.
- Depending on the severity, fleet managers will dispatch mobile response units/technicians to examine and repair or haul away the vehicle. In all cases, the self-driving vehicle's ADS will remain disabled until post-crash system checks are completed.

# VALIDATION AND TESTING

**Our validation and testing methods ensure that the self-driving vehicle minimizes risks during operation.**

In more than a century of engineering and manufacturing, Ford has developed a repository of tests designed to measure performance, quality and safety. Our System Safety process identified safety risks at the beginning of our self-driving vehicle development, created a robust architecture to mitigate them, and generated requirements to satisfy those conditions. Validation and Testing procedures close the loop on this process, using data from testing to vet and improve system, sub-system and component performance as we steer our self-driving vehicles toward deployment on public roads.

Ford and Argo AI use a proven three-step method for verification and validation: simulation, closed-track testing and real-world testing. Our self-driving vehicles undergo rigorous testing, including verification of requirements through Model in the Loop (MIL), Software in the Loop (SIL), Hardware in the Loop (HIL) and fault injection at every level. MIL provides virtual testing in the absence of hardware. SIL provides target code testing in a simulated environment. HIL provides complete component and subsystem hardware testing.

Fault injection purposely introduces faults into systems to test the robustness of the safety strategy to random failures. This provides a holistic, multi-layered approach to fault identification and elimination. Validation includes these testing efforts to cover a variety of use cases and scenarios that self-driving vehicles will encounter. As we test our system, we continually improve our software through our engineering processes, which include machine learning and testing the software against our safety and performance requirements.

In closed-track testing, test specialists are placed behind the wheel on a simulated urban course and subject the vehicles to edge cases and difficult situations. Deliberate fault injection into fail-functional components, such as braking and sensors, tests the system's ability to transition to an MRC during malfunctions, with test specialists able to retake control at any time. Also, during this phase, our vehicles endure Electromagnetic Compatibility (EMC) testing, durability testing, and environmental testing to validate the robustness of the OEDR system.

In the final stage, real-world testing generates the miles logged and evasive maneuvers encountered to either validate system safety or to refine requirements with fresh data for simulations. In later phases of development, we will test the vehicle's ability to independently perform safety fallback maneuvers with the goal of removing test specialists when the ADS is ready.

Not all mileage is created equal: with millions of miles available for training sets from our partners at the Virginia Tech Transportation Institute, we are working to collect novel data while working with the industry to create baseline datasets for simulation. Going forward, data collection will be in accordance with our event-driven storage and retention policies as defined in Data Recording (*see page 32*). Continuous testing and system improvements using multiple sources will help to ensure the ADS becomes even safer.

# HUMAN MACHINE INTERFACE

**The human machine interface (HMI) refers to the design of interactions between the self-driving vehicle and people, both inside and outside of the vehicle.**

It all seems so natural: the driver's seat, the steering wheel, the brake and the accelerator. But what it means to drive a car is the product of more than a century's worth of design and engineering decisions. So, what will happen when drivers become passengers? Thoughtful consideration of the Human Machine Interface (HMI) of self-driving vehicles will help foster their public acceptance.

Trust depends on many things, and communication is key. How our self-driving vehicles welcome customers and relay information about their trip or delivery will play a large part in the acceptance of self-driving vehicles. The same is true for safety: how the vehicle communicates its status and intentions in case of a fault and fallback to an MRC is a critical consideration. As we test our self-driving vehicles' future service, we are already at work creating an interface that inspires trust at every step.

In a ride-hailing experience, when the vehicle arrives, customers are welcomed inside after their identities are confirmed by the vehicle. Once inside and briefed on both the trip ahead and safety features, including a reminder to buckle up, passengers will press a button on a touchscreen accessible from each row of seating that indicates they're ready to go. Information will be delivered via text, graphics, and audio. Throughout the ride, situational awareness information such as the vehicle's environment, location and route will be provided to the rider through the HMI. Once at the rider's destination, the vehicle notifies them when they may exit the vehicle.

Ford has helped develop the AVSC Best Practice for Passenger-Initiated Emergency Trip Interruption and used it to inform the development of our user experience. Should a rider decide an unplanned stop is necessary, our vehicle offers a pullover request interface at two levels. The convenience pullover option within the HMI will trigger a stop at a nearby available pullover location within the vehicle's ODD. The Passenger-initiated Emergency Stop button will bring the vehicle to a rapid stop and prompts a call from an AVCC representative to provide assistance.

Alternatively, should a malfunction or crash occur and the vehicle is forced into a fail-functional or fail-safety mode, the vehicle will explain if an emergency stop is necessary or if it is otherwise unable to complete the trip. At this point, the vehicle will call an AVCC representative who will be able to provide more detailed responses.

In the case of goods delivery, Ford has tested vehicles equipped with secure compartments. For example, a business representative would type an access code into a touchscreen mounted on the exterior of the vehicle, then place the order contents inside. When the vehicle arrives at its destination, the receiving party receives a notification indicating their order is ready for pickup. Upon meeting the vehicle at the curb, they enter their own access code into the touchscreen, and the vehicle compartment opens.

Self-driving vehicles have potential to improve vehicle safety and personal mobility for those whose needs may not be easily met by existing transportation services.

We are engaged in many initiatives to understand how we can address the unique needs of all of our customers. We acknowledge we don't have all of the answers now, but we are committed to continually improving the experience for all customers.

These efforts are informing the ways in which we are developing our vehicle interfaces, including the audible and visual cues provided in our apps and in-vehicle displays, which will help customers with visual and hearing impairments.  With our service partners at our side, we will continue to learn about the diverse needs of our customer base and work to provide new solutions to their mobility needs.

# CONSUMER EDUCATION AND TRAINING

**Proper education and training are essential throughout the deployment of our self-driving vehicles**

We have cars on the road today with a variety of our Ford Co-Pilot360™ suite of driver-assist technologies. We educate our customers about these capabilities through our driver assist technologies website, Ford's Integrated Sustainability and Financial Report, sales brochures and other printed materials, instructional videos and programs such as Ford Driving Skills for Life, which teaches newly-licensed drivers how to use these features. Given that consumer research by Kelley Blue Book, Autotrader and others demonstrates exposure to driver-assist technologies potentially increases acceptance of self-driving vehicles, we believe our efforts are paving the way for their successful Introduction.

Bringing self-driving vehicles to market requires a thoughtful and sustained effort to teach customers how they work, why they're safe, the value they provide, and how to use them. Ford isn't waiting until our self-driving service launches; we have actively participated in industry education efforts. Among these efforts is the Partners for Automated Vehicle Education (PAVE) coalition, which is dedicated to educating the public about automated vehicles and the increased safety, mobility, and sustainability benefits they can provide.

Furthermore, we are working within the communities where we will operate and encouraging an open dialogue amongst citizens, businesses and city leaders. For example, we have a small working group in Miami of key real estate stakeholders whom we meet with regularly.

***We also recently conducted a business pilot with a local non-profit in Miami where we were able to gather feedback from the community on our moving goods service.***

***While we continue to test and develop our self-driving service, we'll strive to share information about their development milestones through various communication channels, including our blog, Self-Driven and social media platforms.***

As we begin deployments, we will provide the appropriate materials to teach our customers about our vehicles' safety, how our self-driving vehicles work, how to request a ride, how to order and interact with delivery vehicles, and what to expect during the experience.

# FEDERAL, STATE AND LOCAL LAWS

**The System Safety process ensures that our vehicles can meet all federal, state and local laws as well as local regulations and rules of the road.**

Ford's self-driving vehicles are designed from the ground up through our System Safety process to be capable of meeting all applicable federal, state and local laws as well as follow all local regulations and rules of the road. For example, our OEDR system cross-checks traffic signs and signals detected by onboard sensors against map data as well as recognizes other road users to act appropriately, such as stopping for pedestrians.

As mentioned earlier, we take safety seriously, including our obligations to meet Federal Motor Vehicle Safety Standards (FMVSS). Our vehicles will comply with all applicable requirements. In some cases, existing standards are not easily applied to self-driving cars, and for those, especially ones pertaining only to human drivers, we will seek exemptions or interpretations. In their place, we will demonstrate how we intend to provide equivalent or better levels of safety through new approaches. We are currently working with the National Highway Traffic Safety Administration (NHTSA), the Virginia Tech Transportation Institute, and other industry stakeholders to update FMVSS regulations with considerations for the unique features and usage introduced by self-driving vehicles.

In addition to following the rules of the road, we understand self-driving vehicles will also need to follow and interact with the commands of law enforcement, EMS and other safety personnel. To help address some of these challenges, Ford contributed to the development of the AVSC Best Practice for First Responder Interactions with Fleet-Managed Automated Driving System-Dedicated Vehicles (ADS-DVs) and participated in the NHTSA's 2020 AV TEST Panel Discussion: Automated Driving Systems and Rural Safety. Ford works with first responders in our deployment areas and beyond to better understand their unique edge cases and incorporate their feedback into vehicle and operational updates to help address the challenges.

***Ford will also continue its commitment to the environment with self-driving vehicles that meet or exceed all applicable fuel economy and emissions regulations.***

# COMMITTED TO EARNING YOUR TRUST AS WE BUILD THE FUTURE

Ford has been working to earn the trust of our customers for more than a hundred years. And we'll keep working to earn that trust as we move into the self-driving future.

We aren't just building a new kind of car. We see this as an opportunity to be part of improving the transportation systems in our cities to create a better world.

Our customers will always be at the center of our design:
to make sure that every time you use a FORD vehicle or service, you feel confident and safe.

That's how we've earned your trust for years, and will continue this commitment in the future.