ETI ToolTech 2018

Autonomous Vehicles: The Role of HIL (Hardware-in-the-Loop) Simulation in Testing Ford's Autonomous Vehicle Platform

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Automated Driving HIL Simulation

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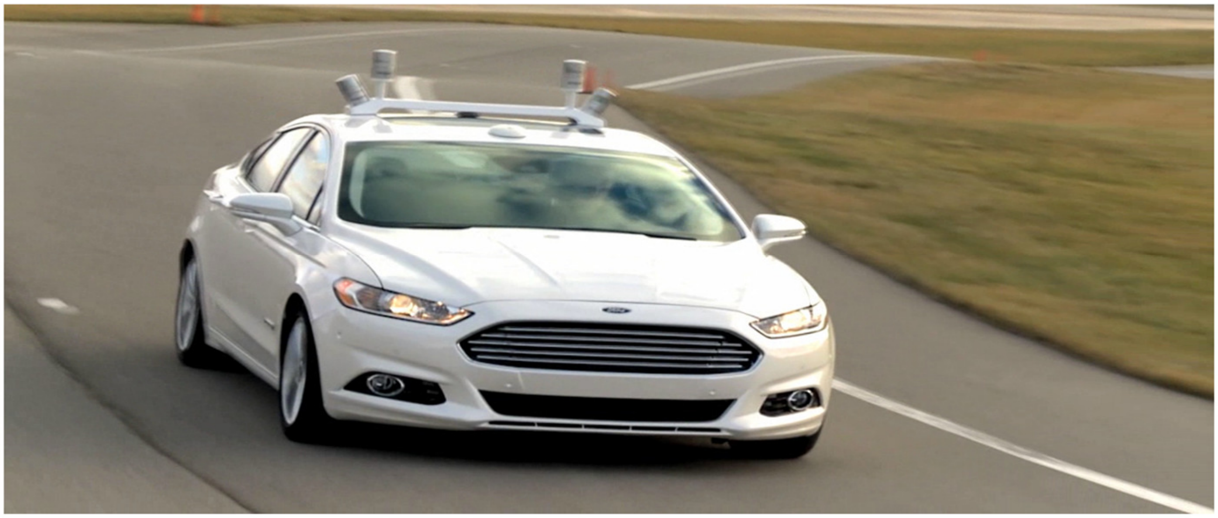
AUTONOMOUS VEHICLES



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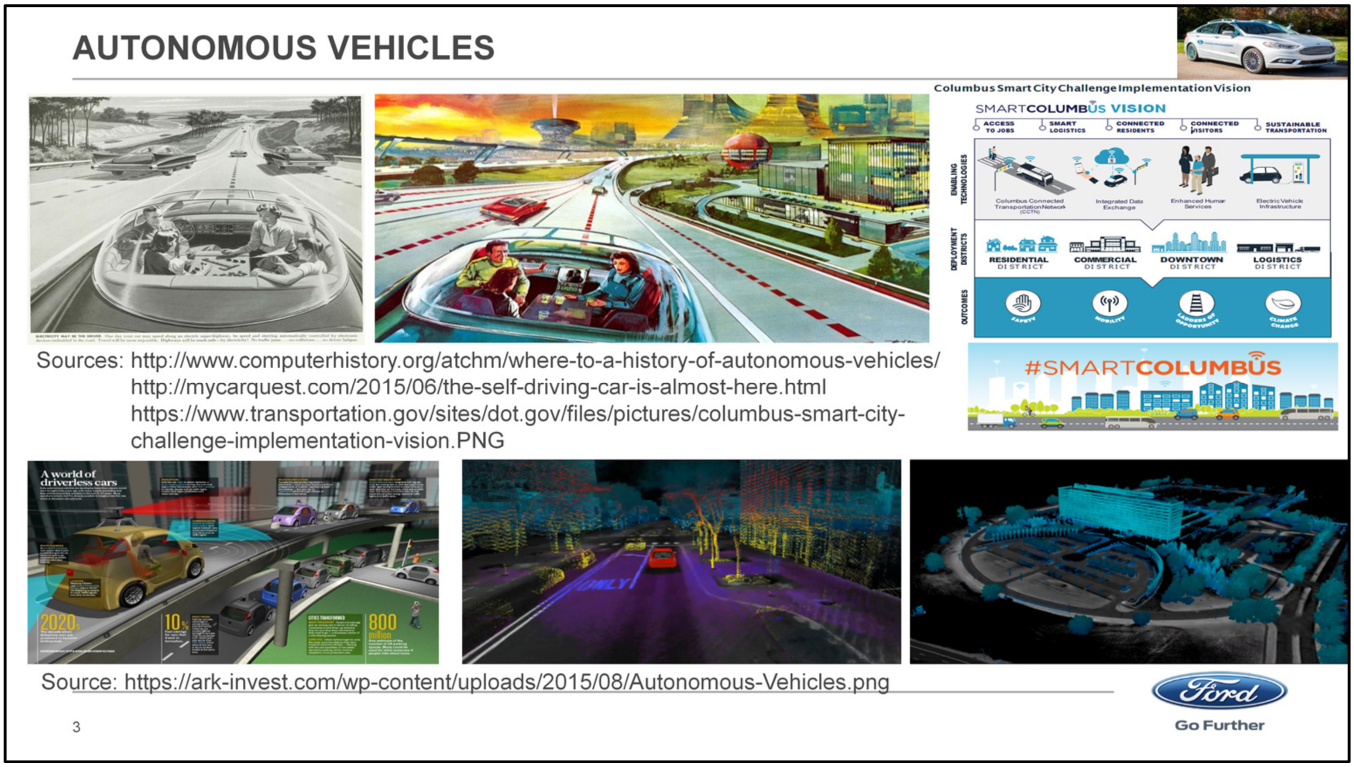
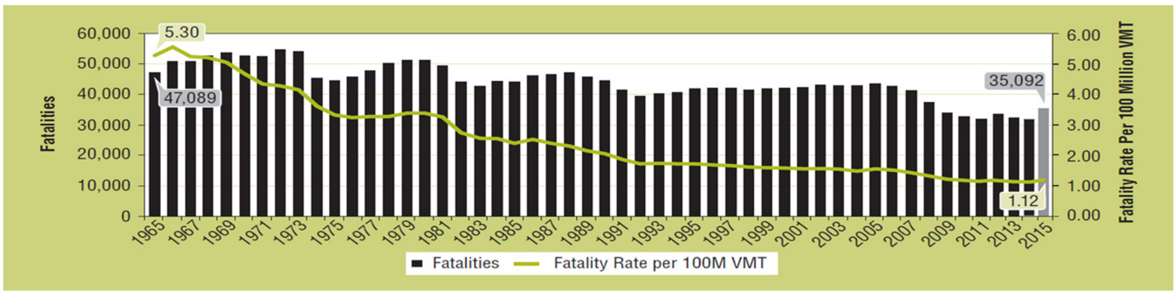


Freestyle, talk of the town, everyone in the automotive industry is not only talking about them, but working on them. They hold the key to the future. Mobility, Smart cities like Columbus. But why? Let’s explore that first.

WHY AUTONOMOUS VEHICLES?

- Increased safety of ALL road users:
  - Passengers
  - Passengers of other vehicles
  - Bicyclists
  - Pedestrians



Source: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812318

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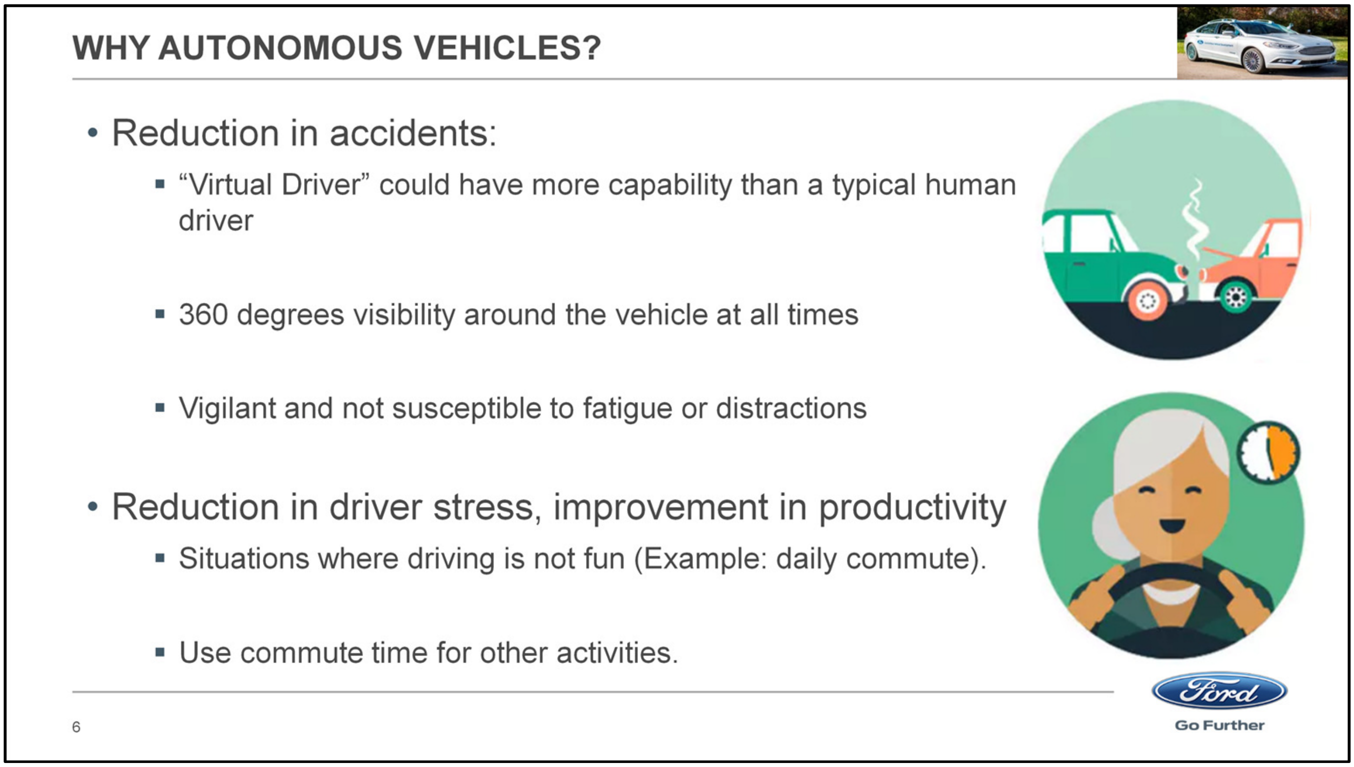
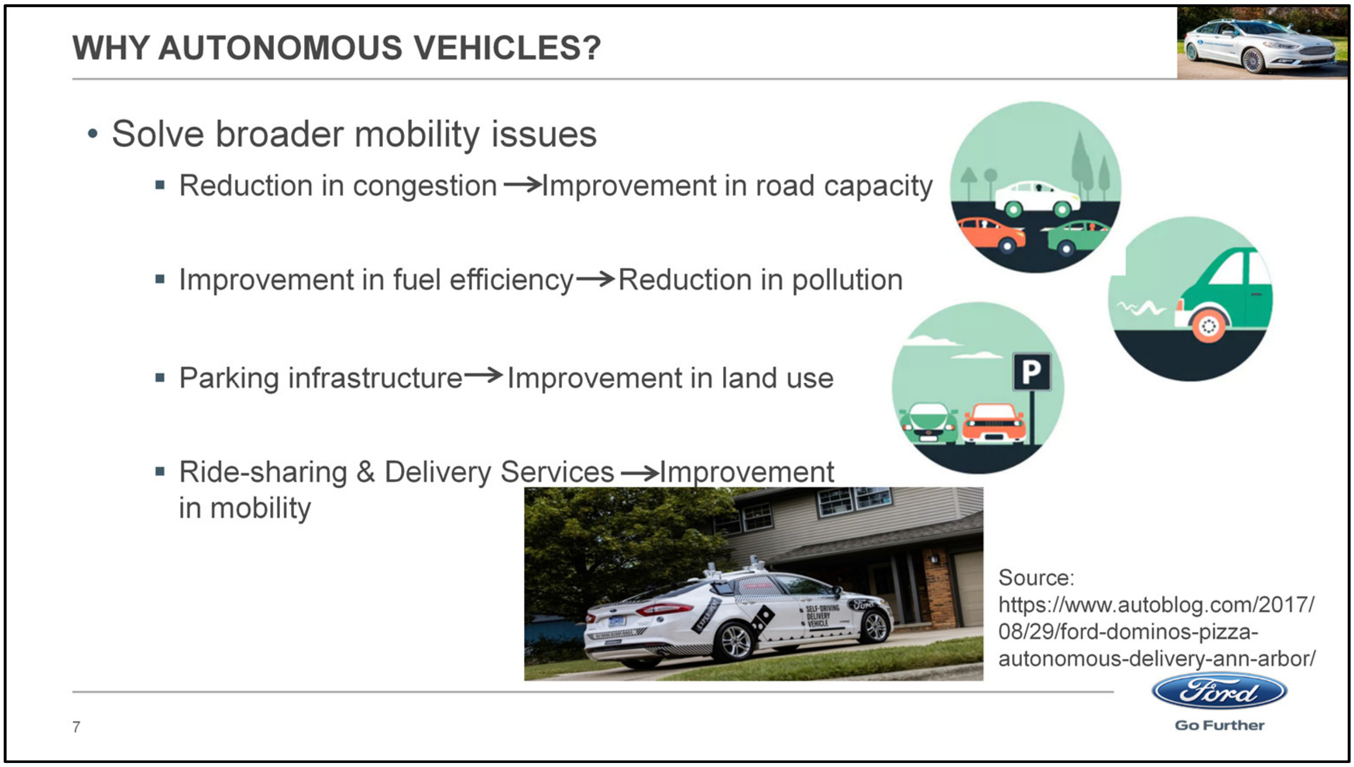
~90% of automobile related deaths in the US are due to driver error.

Zero crashes — so we save lives.
Zero emissions — so our children can inherit a healthier planet.
Zero congestion — so our customers get back a precious commodity: time.
Smart Mobility: The movement of people and goods with…
Car of Today: Increasingly Connected
Car of Tonight: Semi-Autonomous
Car Of Future: Fully Autonomous



More efficient use of existing roads through closer-spaced driving (eg-platooning)
Prior knowledge of road grades/curves/slow traffic to allow for smoother inputs to save fuel and to calm some of the stop-and-go situations
Ridesharing where the vehicle drives itself to you
More automated/efficient/dense parking or off-site parking the car can drive itself to?



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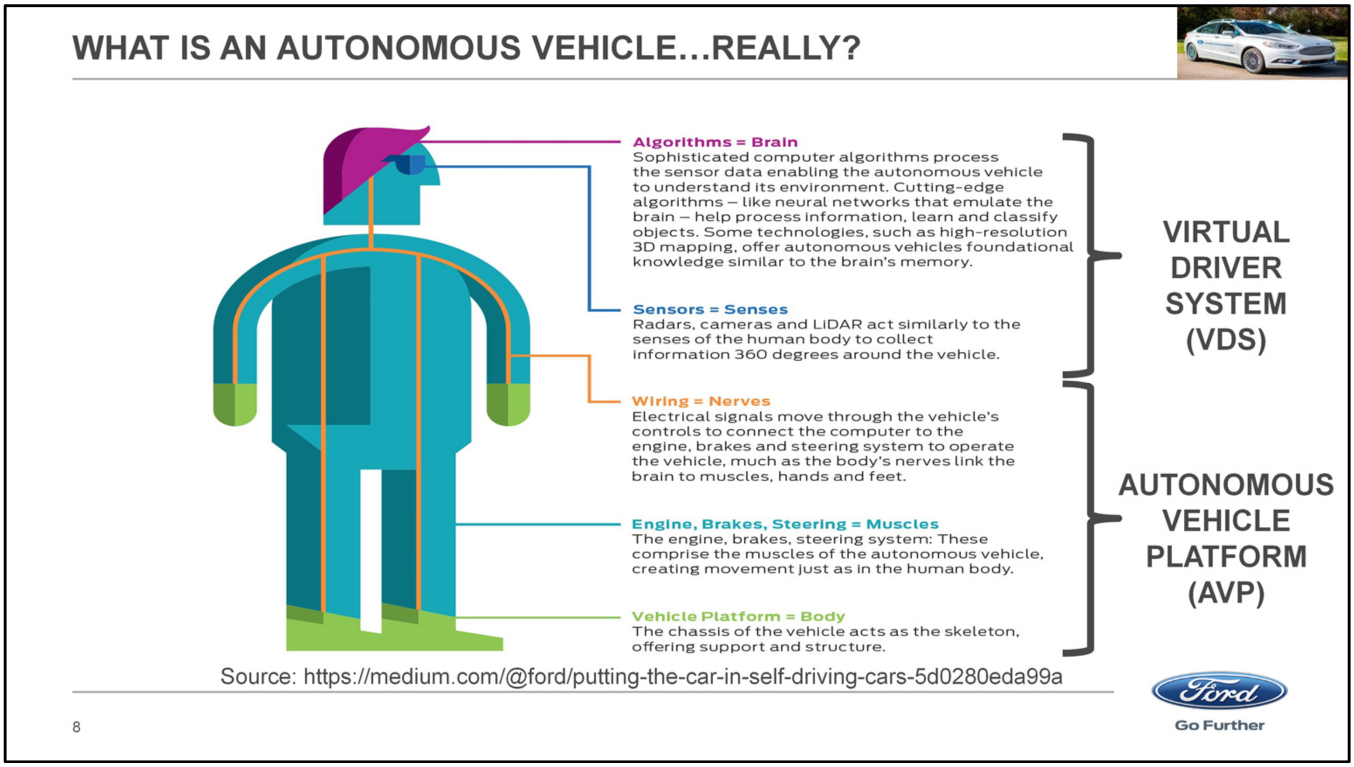

AUTONOMOUS VEHICLE SIMILAR TO HUMAN BODY

THE JOURNEY TO FULL AUTONOMY

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
Human driver **monitors the driving environment**						
0	No Automation	HANDS ON ***AND*** FEET ON	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	HANDS OFF ***OR*** FEET OFF	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	HANDS ***AND*** FEET OFF; EYES ON	**System**	Human driver	Human driver	Some driving modes
Automated driving system **("system") monitors the driving environment**						
3	Conditional Automation	HANDS, FEET, EYES OFF; BRAIN ON	System	**System**	Human driver	Some driving modes
4	High Automation	HANDS, FEET, EYES, BRAIN OFF	System	System	**System**	Some driving modes
5	Full Automation	HANDS, FEET, EYES, BRAIN OFF	System	System	System	**All driving modes**

Source: http://standards.sae.org/j3016_201609/

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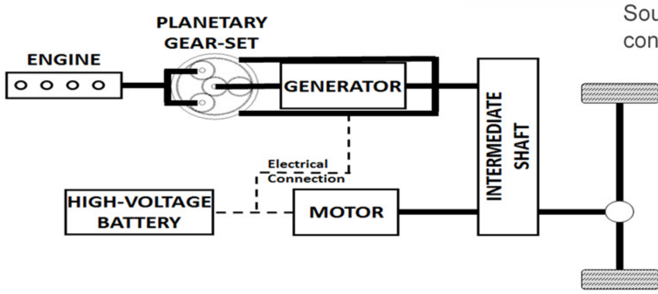
BUILDING AN AUTONOMOUS VEHICLE: VEHICLE

- 2017 Ford Fusion Hybrid

Source: http://steeringnews.com/wp-content/uploads/2014/11/Ford-Mondeo-Hybrid-drivetrain.jpg

- “Power-split” type hybrid architecture



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First you need a vehicle. Ford is using the 2017 Ford Fusion Hybrid as the platform for the autonomous vehicle.
Description of Ford Fusion hybrid architecture, power-split, HV battery, generator, motor,
The interface for actuation is more convenient.

BUILDING AUTONOMOUS VEHICLE: SYSTEM REDUNDANCIES

- Most electronics systems such as ABS and EPAS (power steering) have inherent redundancies in place due to the presence of the driver.
  - If ABS or EPAS fail, the driver is still able to actuate the brakes or steering physically with the loss of electronic assist features
- For SAE Level 4 autonomous vehicles, redundancies will be required
  - Driver not in the loop at all
  - All vehicle control handled by autonomous system
  - Mitigate failure of important components and systems

Level	Name	Driving	Monitoring	Fallback
4	High Automation	HANDS OFF, FEET OFF	EYES OFF	BRAIN OFF

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- To improve the availability and reliability subsystems for higher levels of vehicle automation, the use of redundancy is one approach to achieve fault tolerance [18]. This may include redundancy of components such as sensors, actuators, power supplies, communication buses, and controllers.
- The components and systems of most vehicles on the market today are designed to be fail-safe, i.e. if a single component fails the corresponding system goes into a safe state.
- However, for SAE Level 4 autonomous vehicles, in which the driver will relinquish all vehicle control to the autonomous system, redundancies will be required to be designed and integrated with the vehicle architecture in order to mitigate the failure of important components and systems [20].
- SAE Level 4 autonomous vehicles must be designed such that the chassis controls are fail-operational or fail-functional, i.e. if a single controller or actuator fails, the drivability of the vehicle maintained, however with degraded performance.
- In this design, the chassis control systems and their corresponding actuators must have independent and separate sets of components, power lines and communication lines in the event of fault or failure [21].

BUILDING AUTONOMOUS VEHICLE: SYSTEM REDUNDANCIES

- Chassis controls are fail-operational or fail-functional
  - If a single controller or actuator fails, the drivability of the vehicle maintained, however with degraded performance.
- Chassis control systems and their corresponding actuators must have independent and separate sets of:
  - Components
  - Power lines
  - Communication lines

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Go Further

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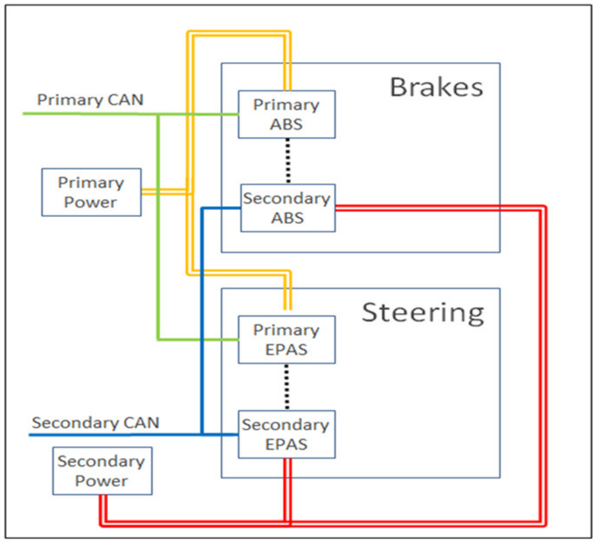
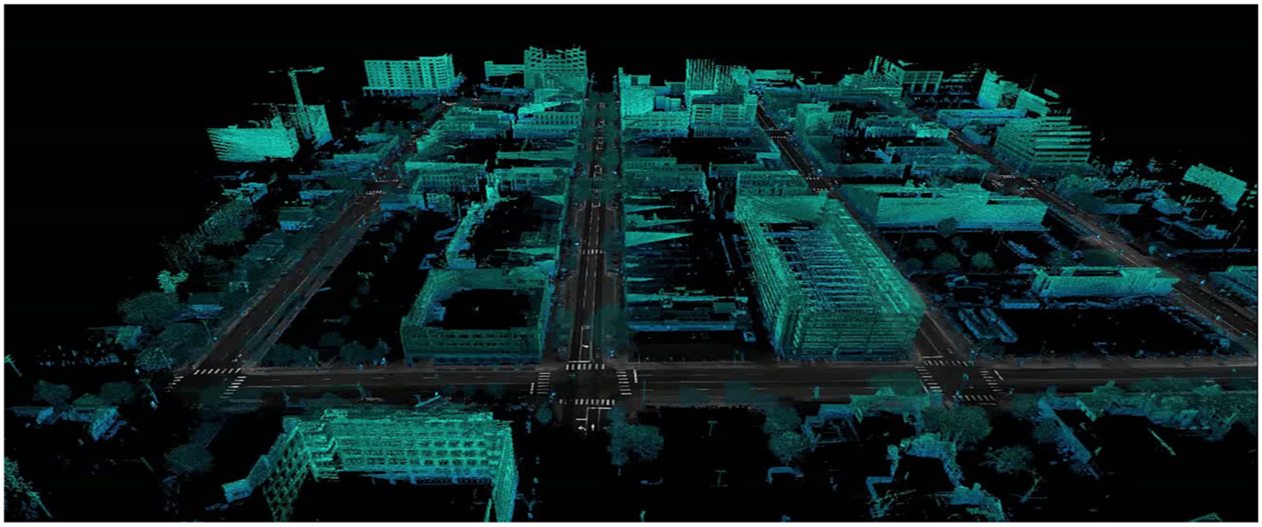
BUILDING AN AUTONOMOUS VEHICLE: SYSTEM REDUNDANCIES



Go Further

BUILDING AN AUTONOMOUS VEHICLE: HIGH-DEFINITION MAPS



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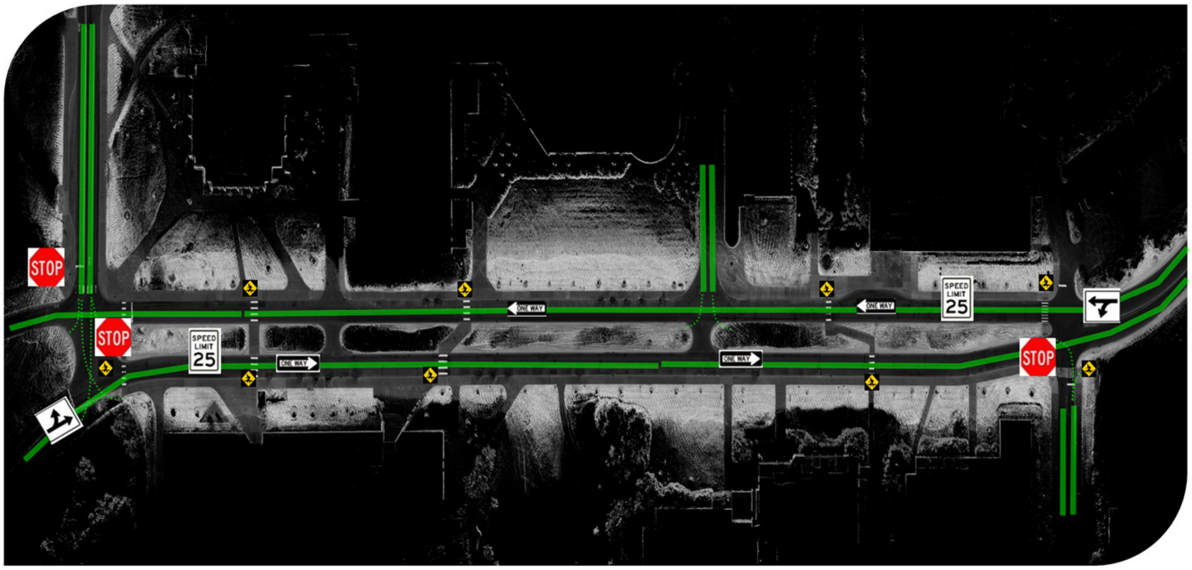
The maps that are particularly built for self-driving purposes are usually called High Definition Maps or HD Maps for short. These maps specifically have extremely high precision at centimeter-level accuracy for precision. This is because the robots need very precise instructions on how to maneuver themselves, how to navigate themselves around the 3D space.

For human drivers, it's much easier, and often much faster, to drive a route that you're already familiar with, because you know generally what to expect — where the intersections are, where the speed limits change, where you need to turn. Driving in an unfamiliar environment is slower and more tentative.
Similarly, self-driving cars operate more efficiently if the map tells them where to look. Stop signs, intersections, lanes, turns, and curbs are all easier to manage if the vehicle knows when and where to expect them.

https://www.linkedin.com/pulse/how-localization-works-self-driving-cars-david-silver/?trackingId=mMTfZ4icEQGx9Zvt1NtzQQ%3D%3D

BUILDING AN AUTONOMOUS VEHICLE: HIGH-DEFINITION MAPS



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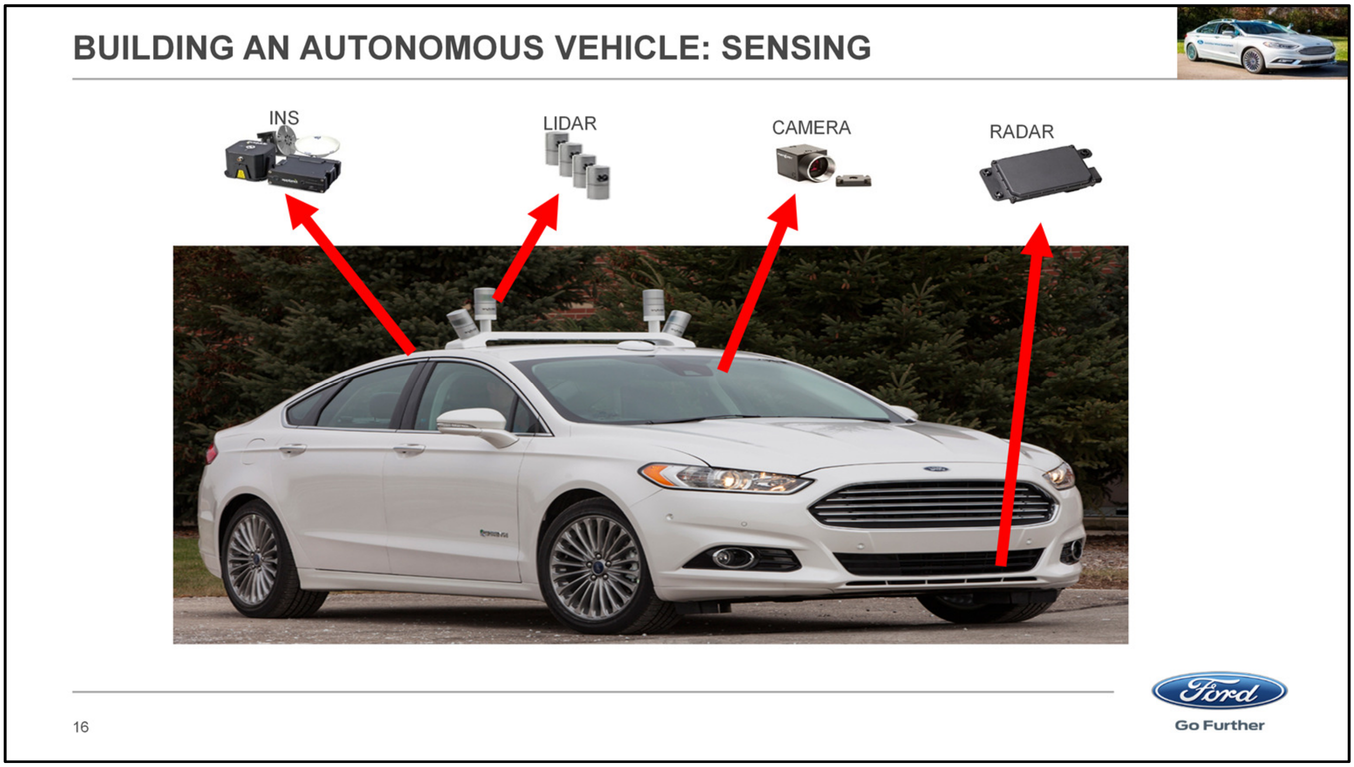
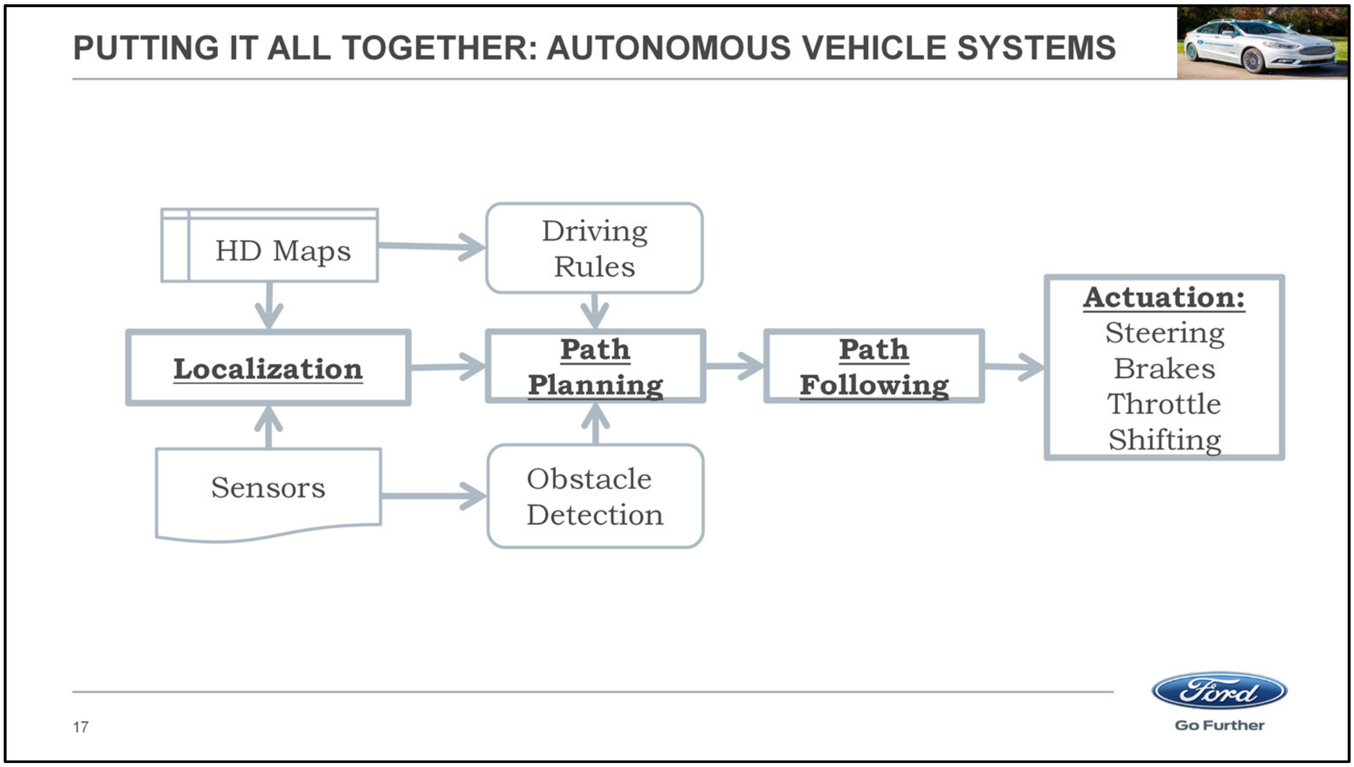


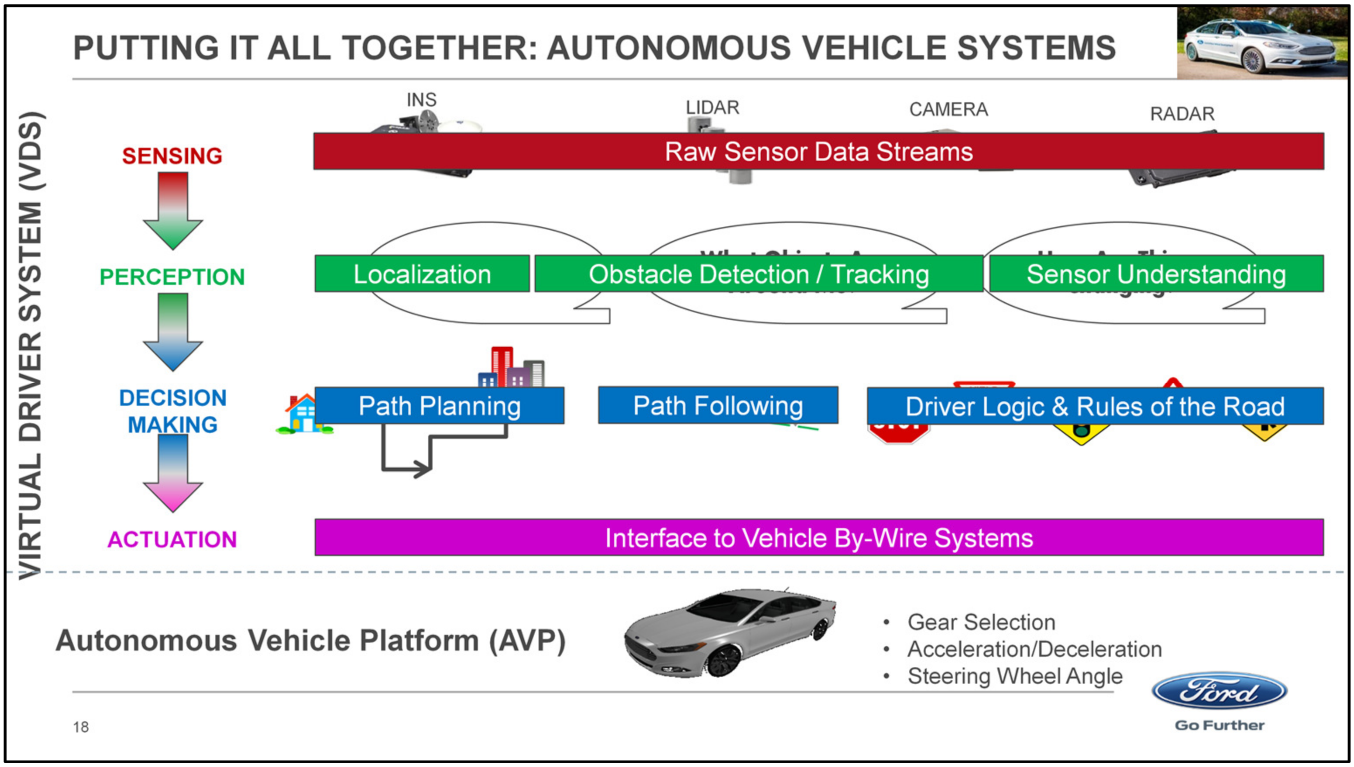
A COMBINATION OF **MULTIPLE SENSORS** ARE UTILIZED FOR AUTONOMOUS DRIVING
INS Inertial Navigation Systems, used on planes, submarines, gyroscopes, accelerometers, etc.



Determining the vehicle's precise position on the map is called "localization". By localizing itself, the vehicle can determine its precise relationship to all of the elements on the map. Is the vehicle in the middle lane or the right lane? How far away is the curb? What about the next intersection?

Path planning component of AV will base decisions off of this localization information. For example, if the car localizes itself in the middle lane of a road, but the motion planner knows a left turn is coming up, then the motion planner will begin preparing the vehicle to shift into the left lane, so it's positioned to make the turn.

https://www.linkedin.com/pulse/how-localization-works-self-driving-cars-david-silver/?trackingId=mMTfZ4icEQGx9Zvt1NtzQQ%3D%3D


PUTTING IT ALL TOGETHER: AUTONOMOUS VEHICLE SYSTEMS
VIRTUAL DRIVER SYSTEM (VDS)
INS
LIDAR
CAMERA
RADAR
SENSING
Raw Sensor Data Streams
PERCEPTION
Localization
Obstacle Detection / Tracking
Sensor Understanding
DECISION MAKING
Path Planning
Path Following
Driver Logic & Rules of the Road
ACTUATION
Interface to Vehicle By-Wire Systems
Autonomous Vehicle Platform (AVP)
• Gear Selection
• Acceleration/Deceleration
• Steering Wheel Angle
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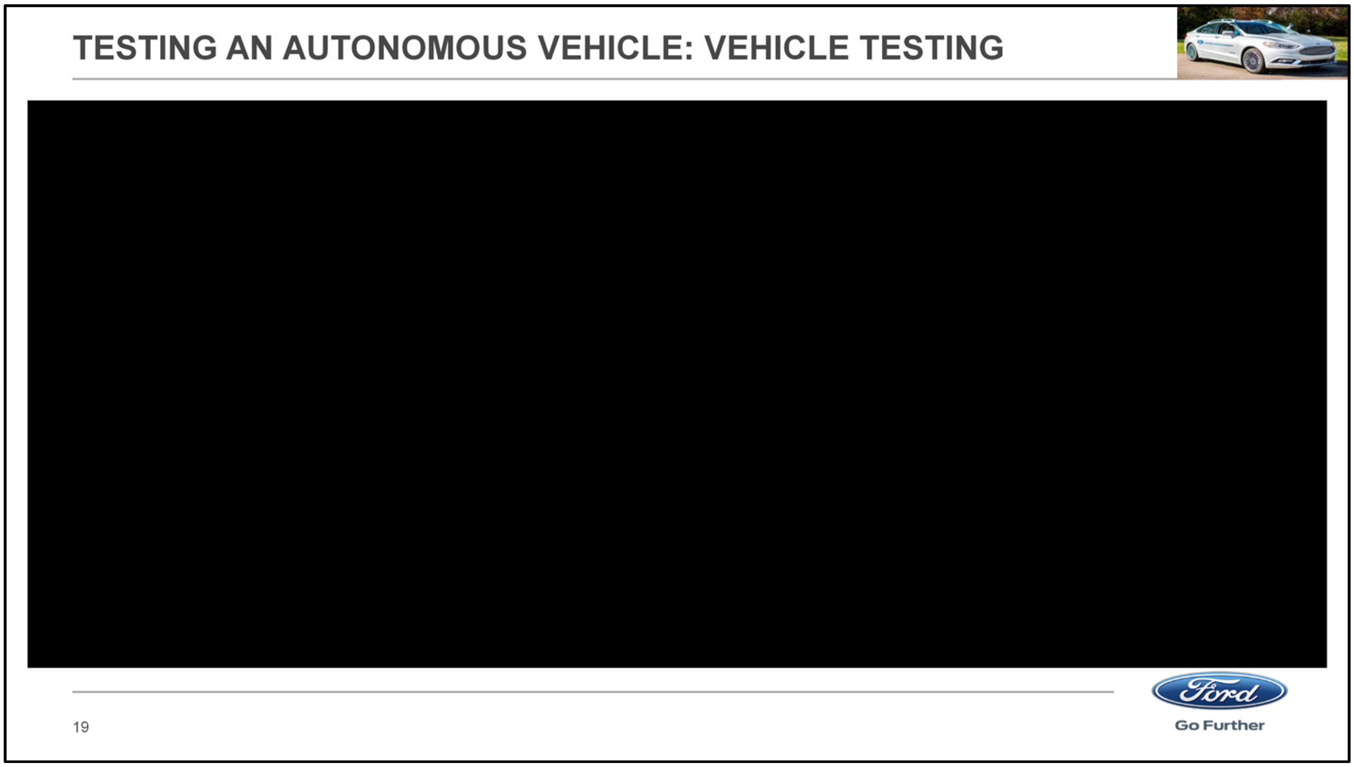


Proving ground for testing CAV, urban driving features like intersections, roundabouts, traffic lights, building facades, highway entrances, tunnels, bridges.

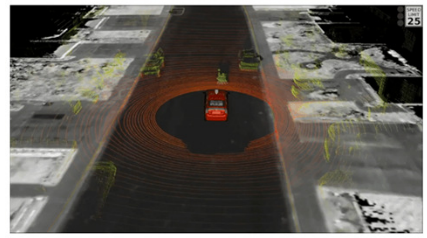
MAIN:
https://www.youtube.com/watch?v=xjPY1JxFGJk

BACKUP:
https://www.youtube.com/watch?v=VWfdt0oCsJg
https://www.youtube.com/watch?v=-ah-p6zIGjw

TESTING AN AUTONOMOUS VEHICLE: SIMULATION

- Challenges in Testing Autonomous Vehicles

  - Unlimited number of real-life traffic scenarios
  - Many unknown factors & human driver out of the loop
  - Exponential growth in testing effort⟶ Hundreds of millions of test km required



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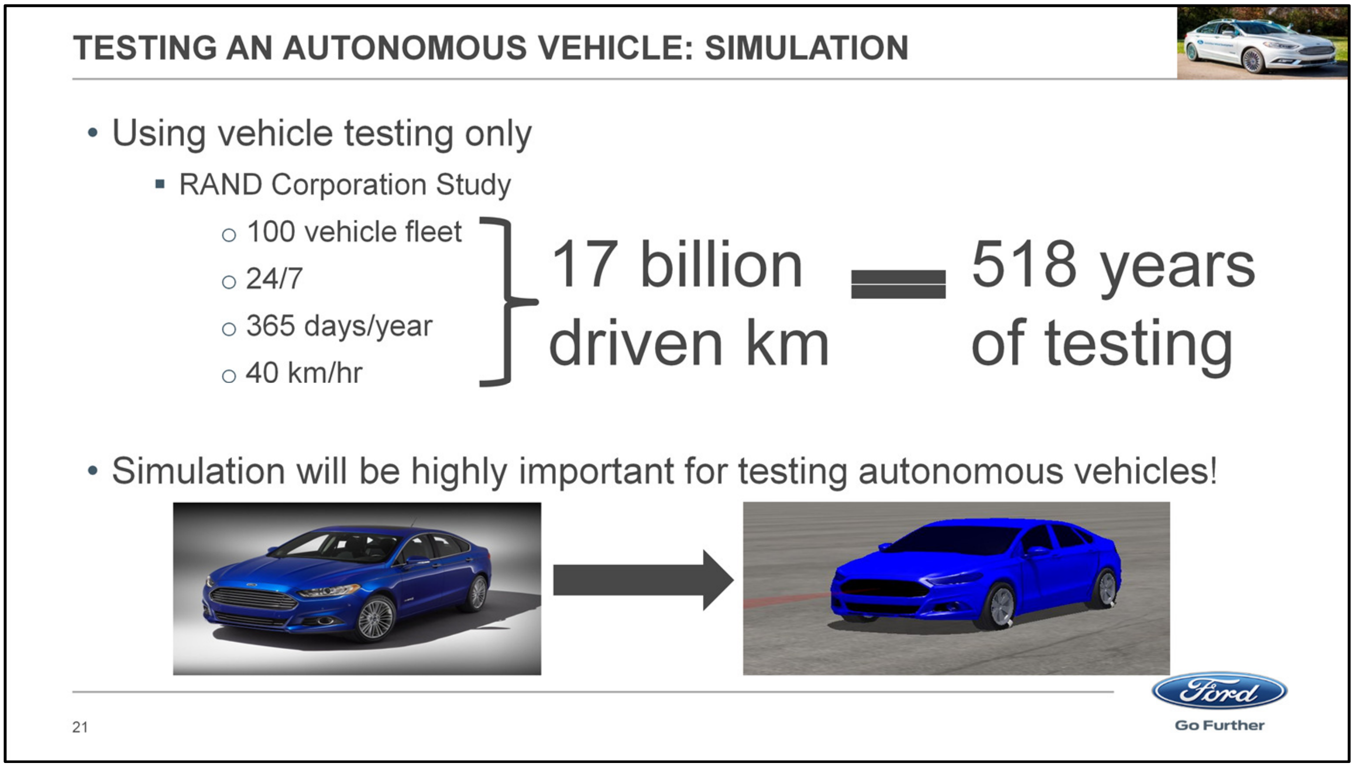
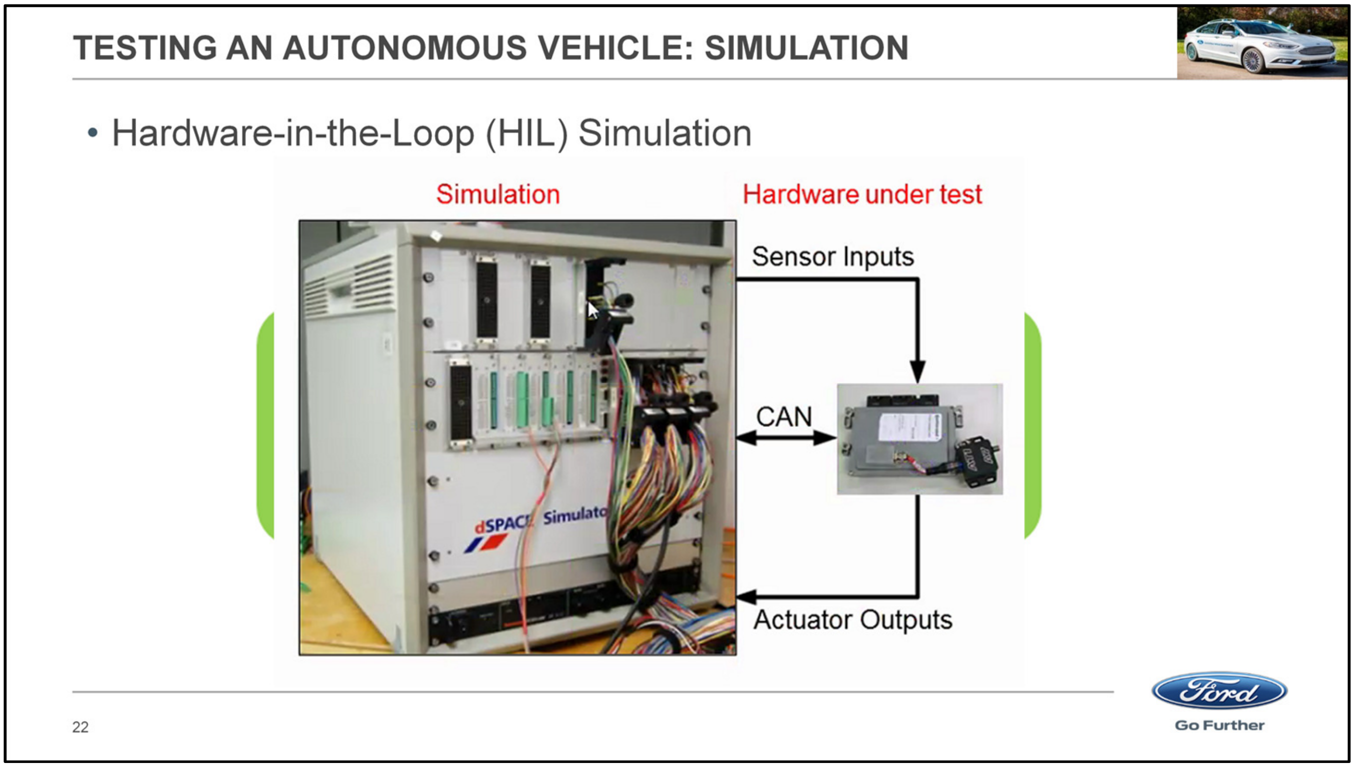
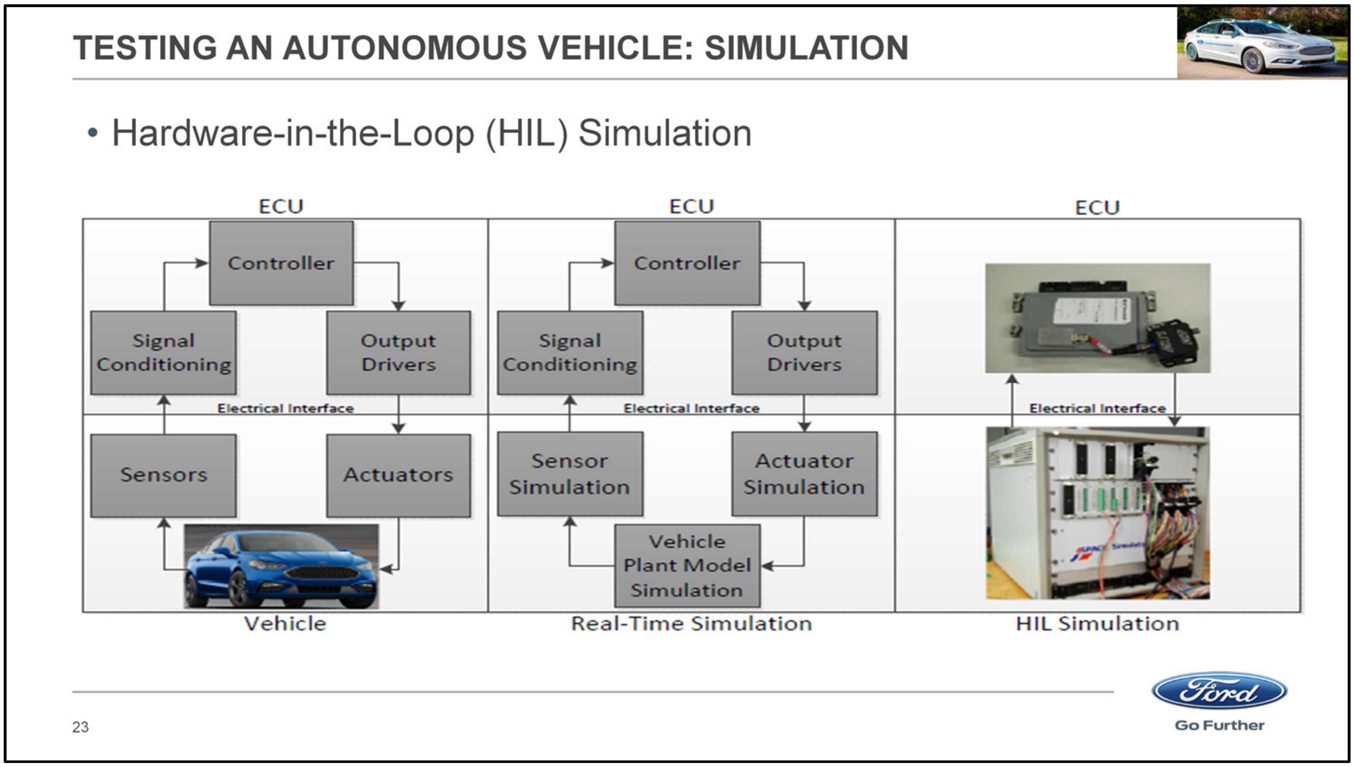


- According to the RAND Corporation, a 100 vehicle fleet running 24 hours a day 365 days a year at a speed of 40 km/hr, would require 17 billion driven kilometers of testing and take 518 years to fully validate the autonomous vehicle software with 95% confidence such that its failure rate was 20% better than the current human driver fatality rate
- Unrealistic and infeasible timescales for software validation
- Alternative testing methods are needed to shorten the validation process such that testing may be conducted in a safe and repeatable manner.



- A HIL simulation provides a test platform where the system under test consists of actual hardware components with the remainder of the system simulated with a real-time simulation platform.
- This is done in combination of using mathematical or physics-based plant models representing the process and dynamic systems along with the physical hardware components, in particular the controllers, which are typically in the form of embedded ECUs.
- These ECUs are provided with similar electrical interfaces of physical signals that would be present in the real system process such that the simulated plant models act as an emulation of the real system process.



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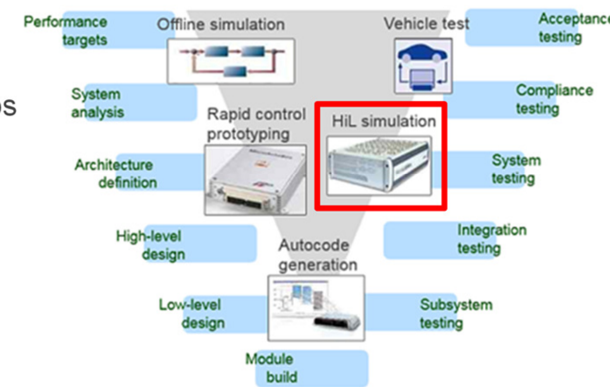
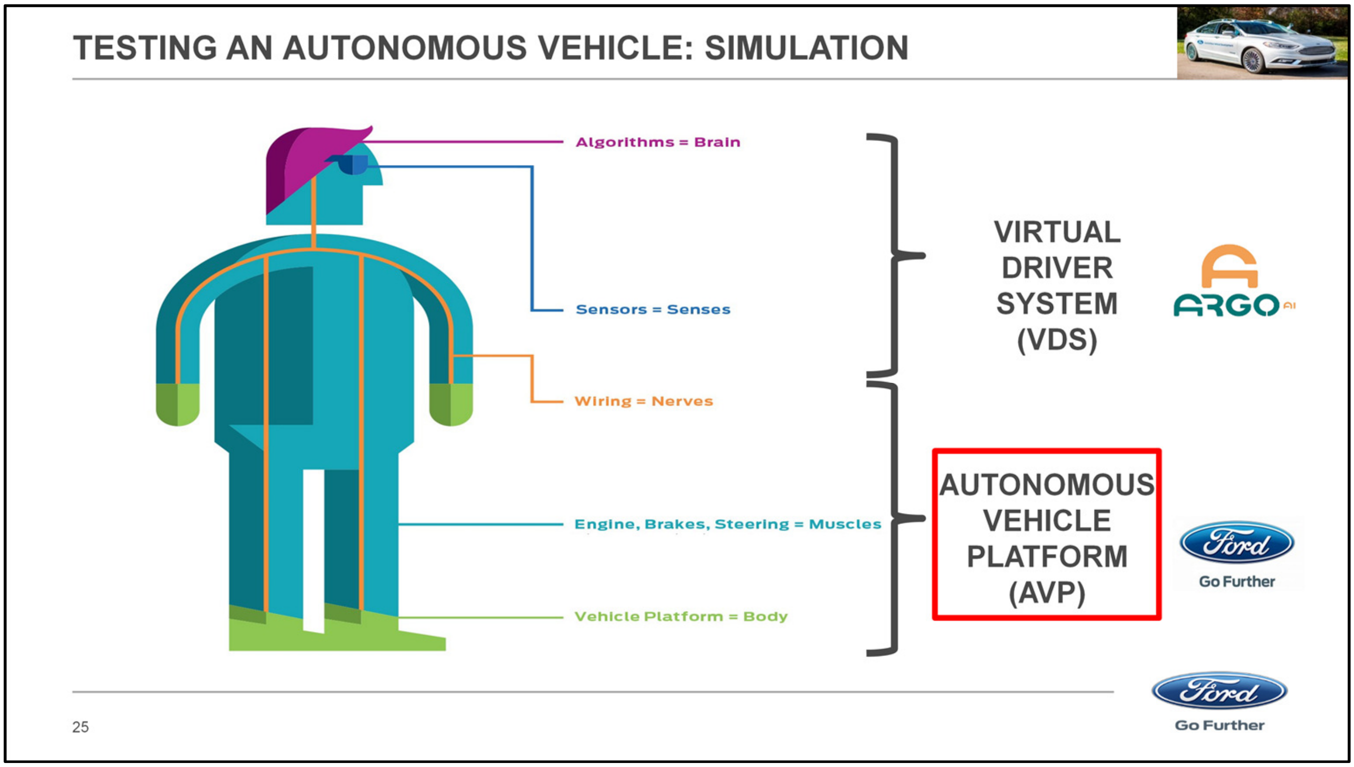
TESTING AUTONOMOUS VEHICLES: SIMULATION

- Hardware-in-the-Loop (HIL) Simulation
  - ECUs tested in a safe, controlled, simulated environment
  - Scalability and repeatability of scenarios
  - Improvement in test consistency
  - Reduction in system variation



Go Further

Hardware-in-the-loop (HIL) testing is a testing method which has become an integral part of control validation in the automotive product development cycle.



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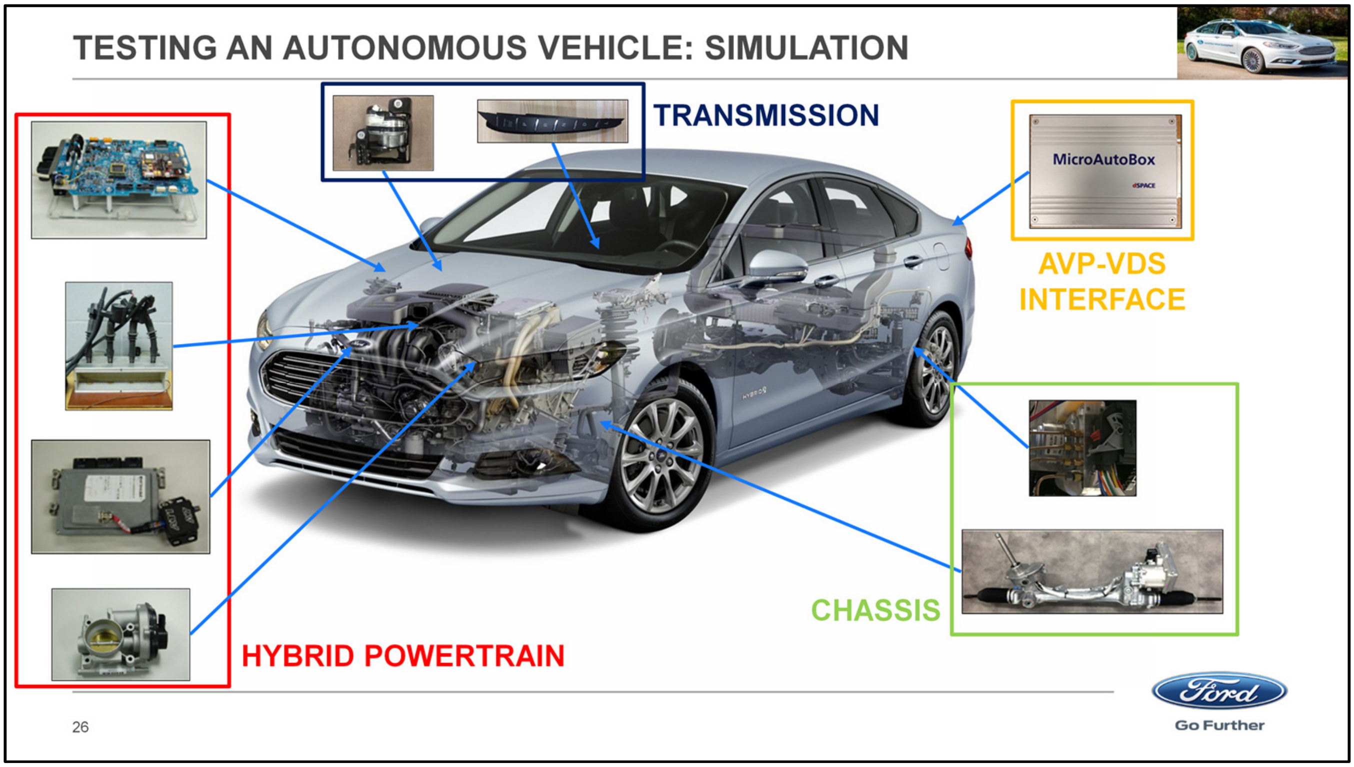
TESTING AN AUTONOMOUS VEHICLE: SIMULATION
TRANSMISSION
MicroAutoBox
AVP-VDS
INTERFACE
CHASSIS
HYBRID POWERTRAIN
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Ford
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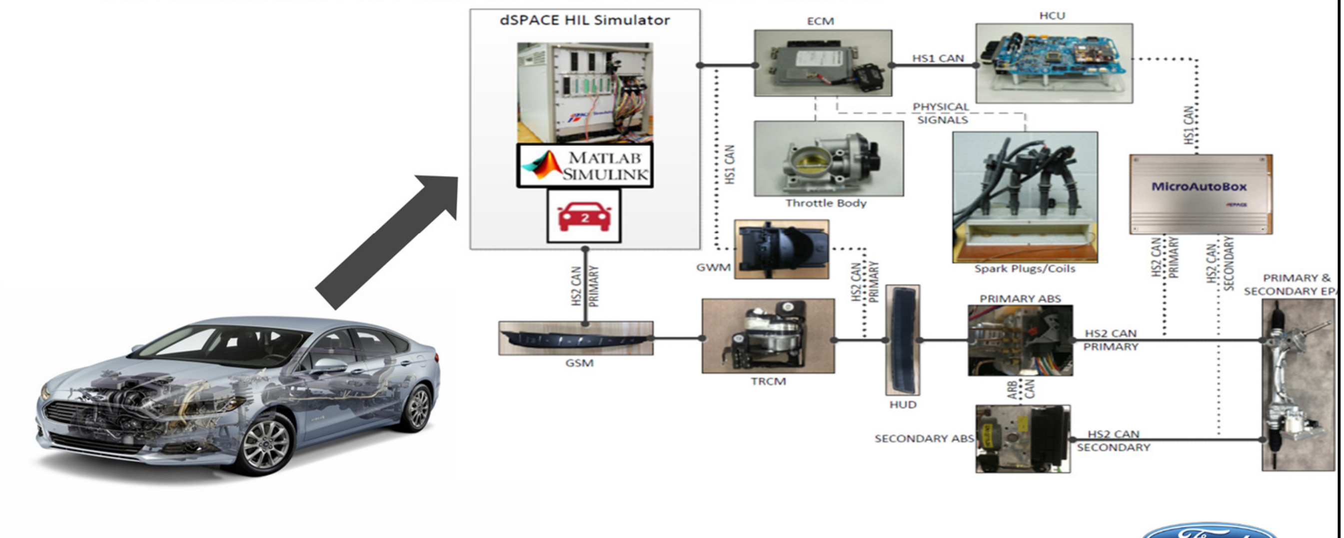
- HIL Simulation of Autonomous Vehicle Platform



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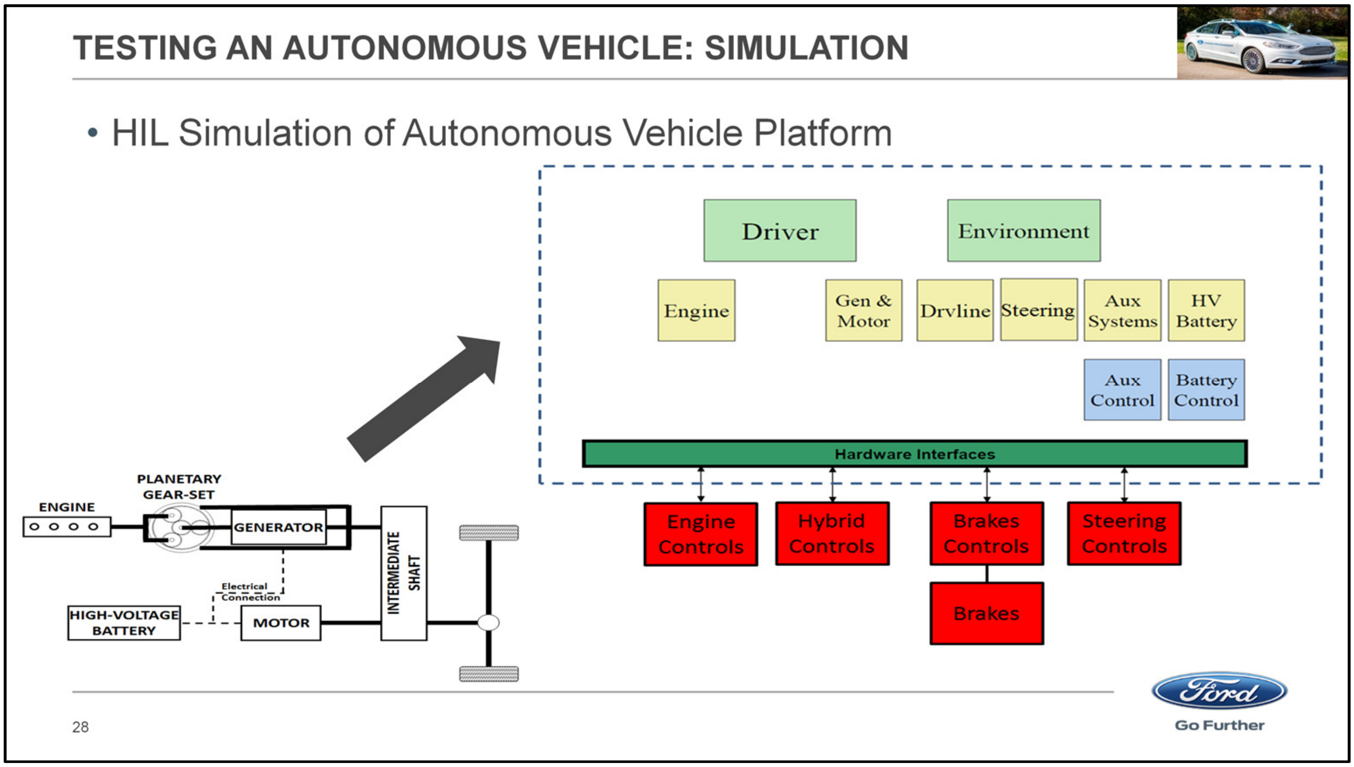
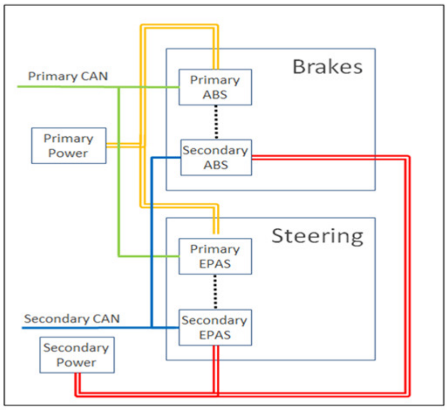
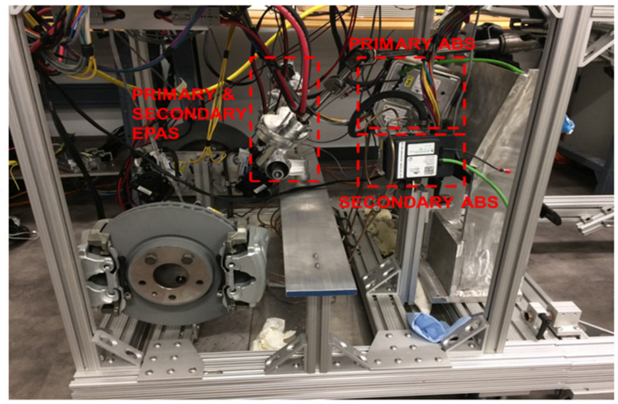


Actuators: EGR, Injectors
Sensors: EGO
Engine: Cylinders, Intake Manifold, Exhaust Manifold, ECT, CHT, EOT

TESTING AN AUTONOMOUS VEHICLE: SIMULATION

- HIL Simulation of Autonomous Vehicle Platform





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Go Further

TESTING AN AUTONOMOUS VEHICLE: SIMULATION

- Using HIL Simulation of Autonomous Vehicle Platform for Testing

Go Further

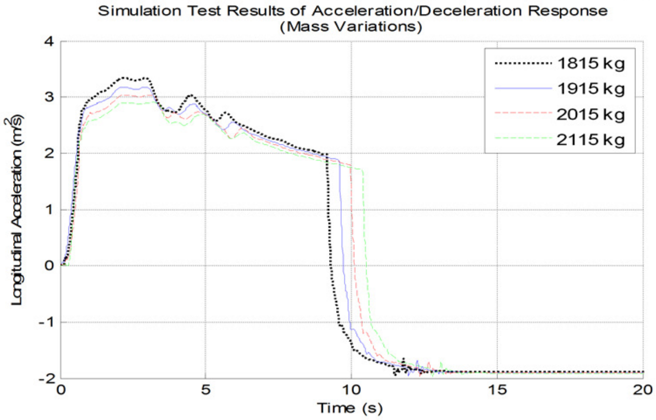
TESTING AN AUTONOMOUS VEHICLE: SIMULATION

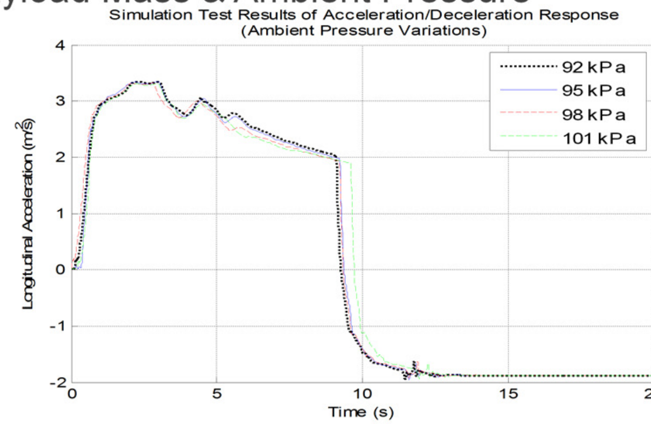
- Using HIL Simulation of Autonomous Vehicle Platform for Scenarios

Go Further

TESTING AN AUTONOMOUS VEHICLE: SIMULATION

- Simulations over Disturbances: Payload Mass & Ambient Pressure





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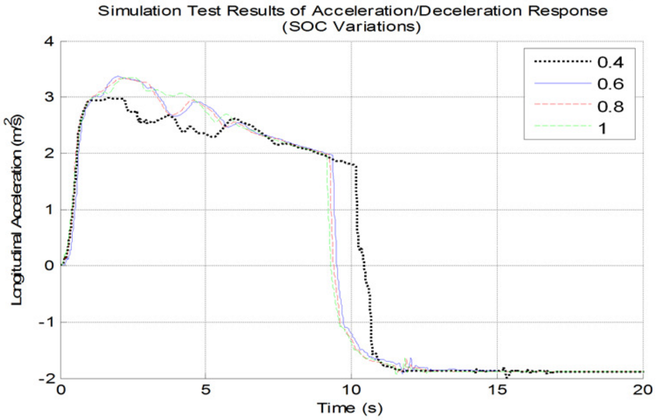
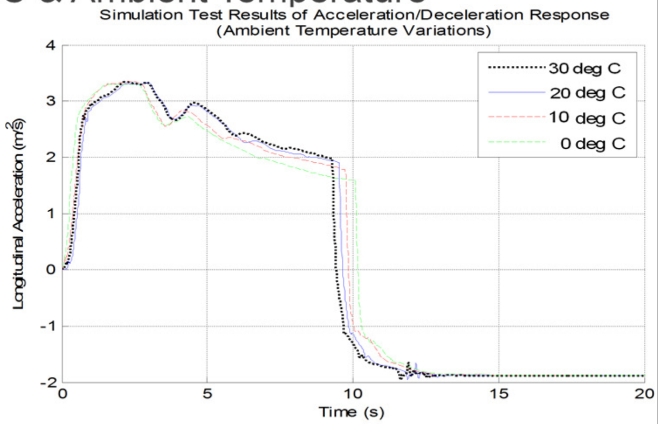
TESTING AN AUTONOMOUS VEHICLE: SIMULATION

- Simulations over Disturbances: SOC & Ambient Temperature

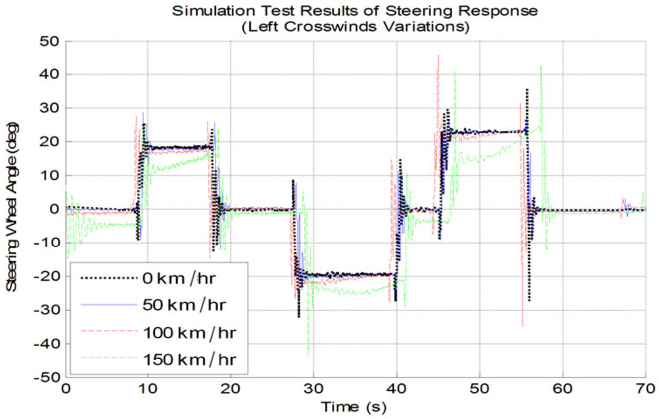


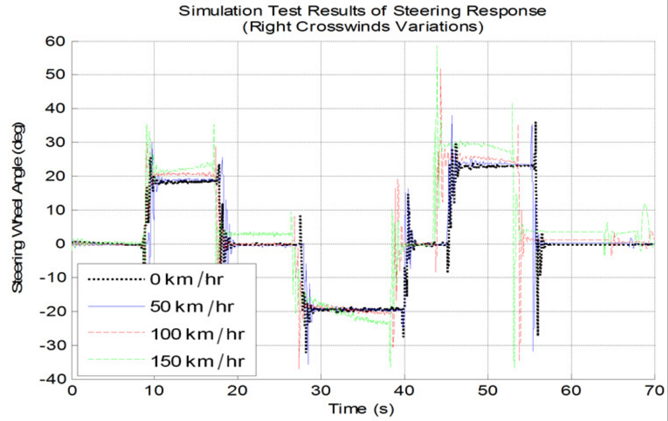


Go Further

TESTING AN AUTONOMOUS VEHICLE: SIMULATION

- Simulations over Disturbances: Crosswinds





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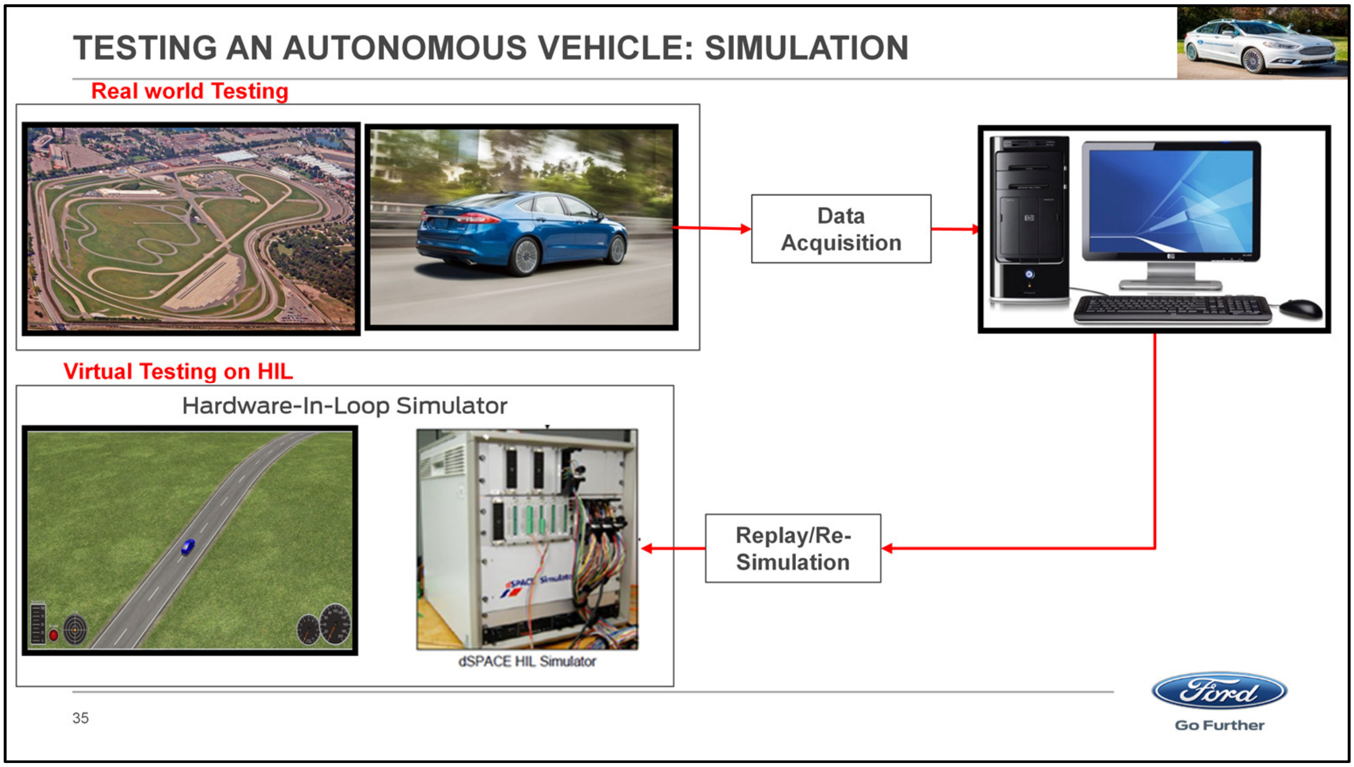
TESTING AN AUTONOMOUS VEHICLE: SIMULATION
Real world Testing
Data Acquisition
Virtual Testing on HIL
Hardware-In-Loop Simulator
Replay/Re-Simulation
dSPACE HIL Simulator
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Ford
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TESTING AN AUTONOMOUS VEHICLE: SIMULATION

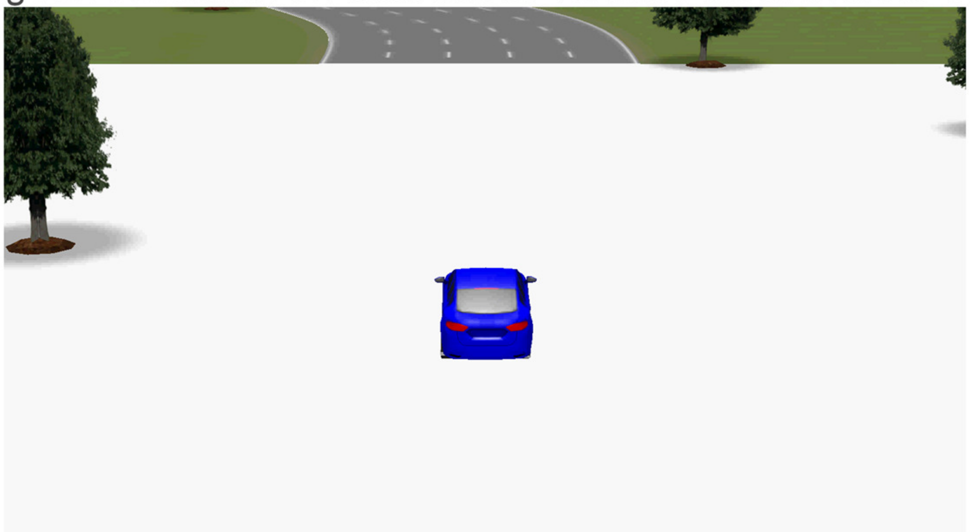
- Using HIL Simulation of Autonomous Vehicle Platform for Re-Sim

Vehicle Run (Vehicle Run.mpg)

Go Further

TESTING AN AUTONOMOUS VEHICLE: SIMULATION

- Using HIL Simulation of Autonomous Vehicle Platform for Re-Sim



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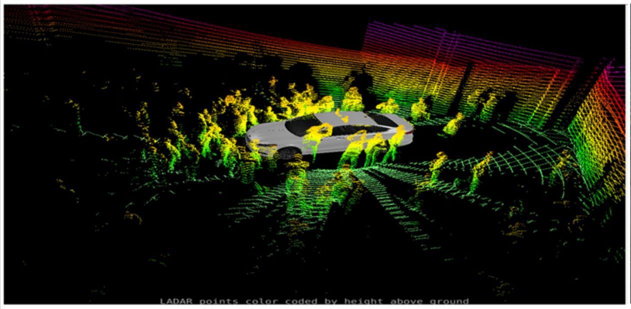
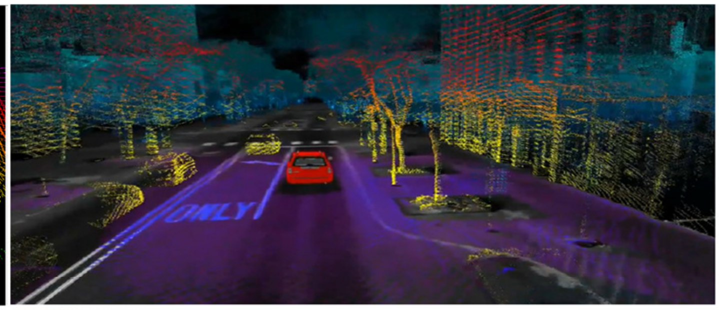
THE FUTURE IS COMING SOON!





<u>BEFORE</u>: HAVE YOU DRIVEN A FORD LATELY ??

<u>SOON</u>: HAS A FORD DRIVEN YOU LATELY ??

QUESTIONS???

Go Further

RESOURCES

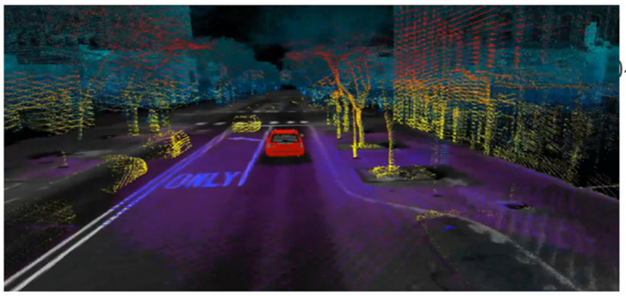
- **SAE Technical Paper** on “Powertrain and Chassis Hardware-in-the-Loop (HIL) Simulation of Autonomous Vehicle Platform”
  - SAE Technical Paper #: 2017-01-1991
- **SAE Technical Paper** on “Hardware-in-the-Loop (HIL) Implementation and Validation of SAE Level 2 Autonomous Vehicle with Subsystem Fault Tolerant Fallback Performance for Takeover Scenarios”
  - SAE Technical Paper #: 2017-01-1994
- **SAE Technical Paper** on “Real-Time Implementation and Validation for Automated Path Following Lateral Control Using Hardware-in-the-Loop (HIL) Simulation”
  - SAE Technical Paper #: 2017-01-1683

BACKUP SLIDES

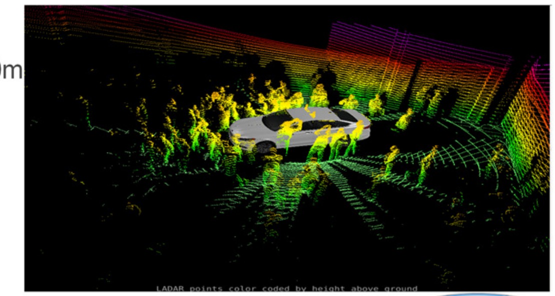
Go Further

BUILDING AN AUTONOMOUS VEHICLE: SENSING

- LIDARs
  - Sends out laser pulses which bounce off objects and return to the sensor.
  - The time between the pulse and the returning signal provides distance to the object.
  - Range accuracy of ~2cm, allows for precision mapping and localization.
  - Range varies with the reflectivity of the surface.



-120m



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2200 pulses per rotation and 10 rotations per second.
~ 2.8 million range measurements every second!

THE JOURNEY TO FULL AUTONOMY

Automation Levels	No Automation Level 0	Driver Assistance Level 1	Partial Automation Level 2	Conditional Automation Level 3	High Automation Level 4	Full Automation Level 5
Scope of Control (hands & feet)	Warnings or Support	Lateral OR Longitudinal Control	Lateral and Longitudinal Control			
Sensing & Response (eyes & brain)	Partial Capability			Complete Capability		
Driver's Role	**HANDS ON *AND* FEET ON**	**HANDS OFF *OR* FEET OFF**	**HANDS *AND* FEET OFF; EYES ON**	**HANDS, FEET, EYES OFF; BRAIN ON**	**HANDS, FEET, EYES, BRAIN OFF**	**HANDS, FEET, EYES, BRAIN OFF**
Operating Conditions	May be limited (GEO-fenced area, Environmental conditions, etc.)					Unlimited
Examples	Forward Collision Warning or Lane Keep Assist	Adaptive Cruise Control or Active Park Assist	Traffic Jam Assist or Fully Assisted Parking Aid		Ford Autonomous Driving Research Vehicles	

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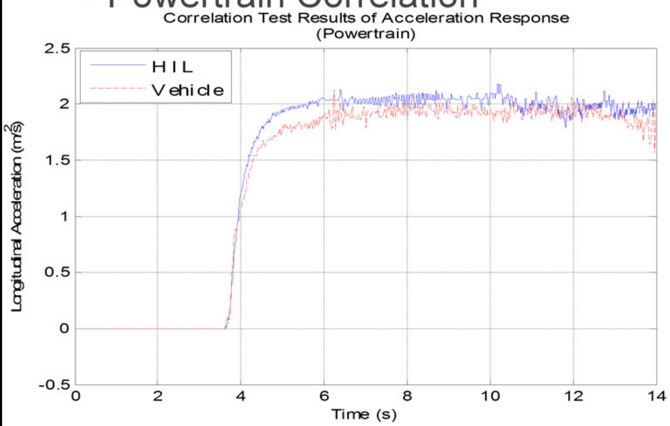
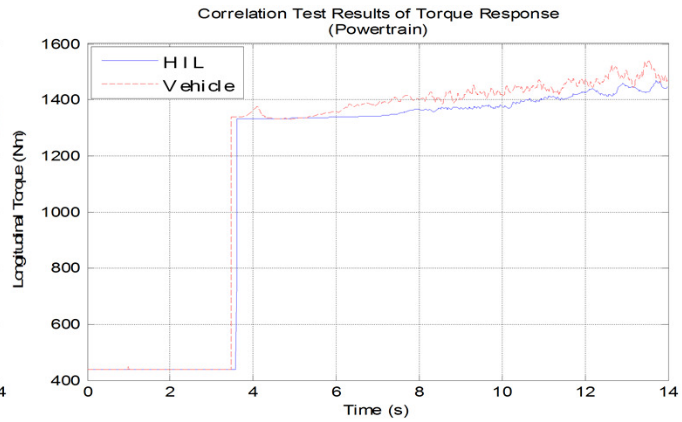
Go Further

TESTING AN AUTONOMOUS VEHICLE: SIMULATION

- Powertrain Correlation

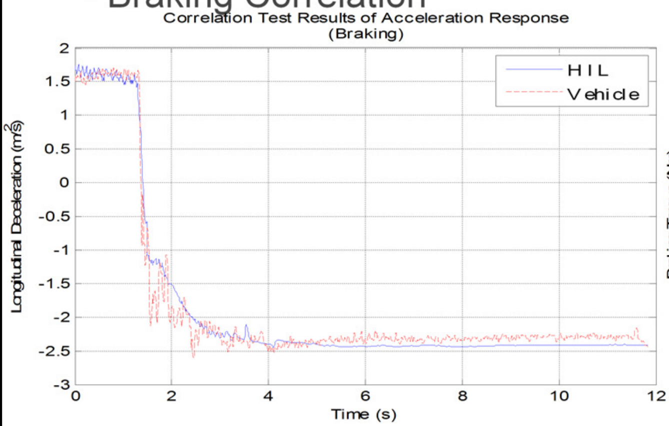


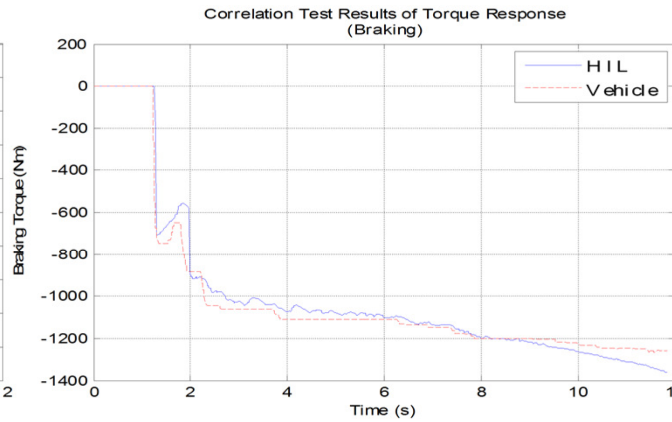


Go Further

TESTING AN AUTONOMOUS VEHICLE: SIMULATION

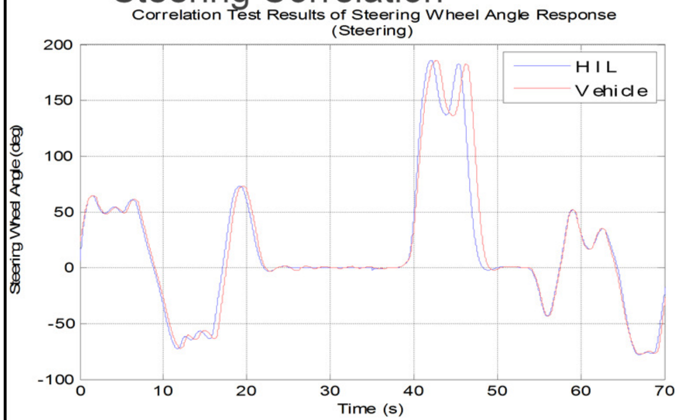
- Braking Correlation

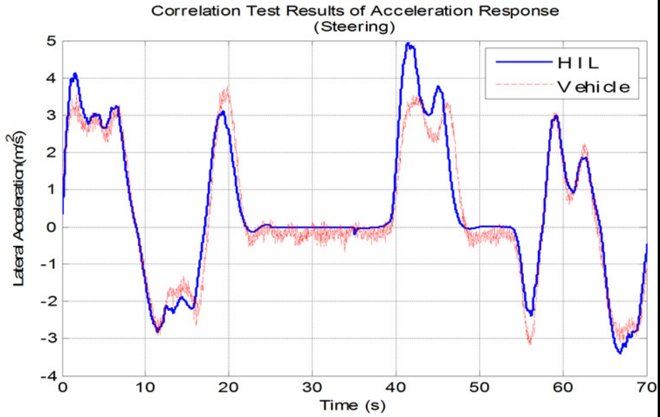




TESTING AN AUTONOMOUS VEHICLE: SIMULATION

- Steering Correlation





Go Further