

Mar 3rd, 10:45 AM - 12:00 PM

## Validation Framework for Autonomous Aerial Vehicles

Mustafa Akbas Ph.D.

*Embry-Riddle Aeronautical University*, akbas@erau.edu

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# **Validation Framework for Autonomous Aerial Vehicles**

**Research Efforts on the V&V of Autonomous Vehicles**

**03/03/2020**

**M. Ilhan Akbas, Ph.D.**

**Assistant Professor of Electrical and Computer Engineering**

**Embry-Riddle Aeronautical University**

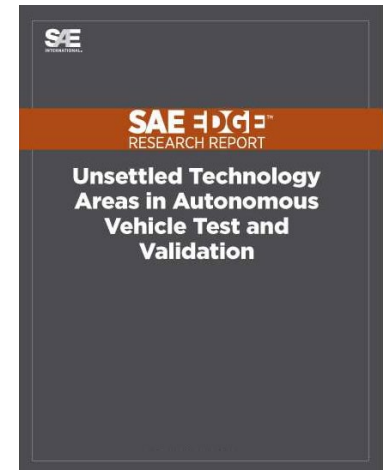
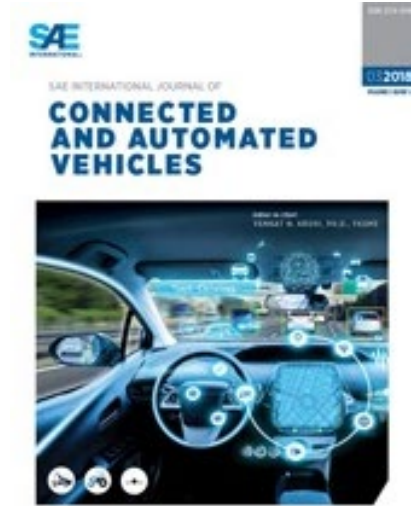
# Outline

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- **About Our Research**
  - **Rise of Autonomy and Challenges**
  - **Validation Framework**
  - **Related Research Themes**
  - **Summary**
-

# About Our Research

- **M. Ilhan Akbas**
  - BS in EE, MS and PhD on Communication Technologies
  - Post Grad Work on Modeling & Simulation Projects
  - Industry Experience in Defense, NATO Projects
- **Research** on AVs, CPS, Intelligent Mobility
- **Projects** from NSF, Cyber Florida, State
- **Published** in SAE, IEEE Trans., ACM
- **Teaching** AV, M&S, Soft. Eng, Networks, Security



# Outline

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- About Our Research
  - **Rise of Autonomy and Challenges**
  - **Testing Framework**
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-

# Self-Driving Cars

**LEAVE THE  
DRIVING  
TO US**

**1960—The Radio Corporation of America and General Motors are proud to present** the future of transport: cars that can drive themselves! You've heard about them for years, but now they're nearly here. Using sophisticated magnetic sensors and radio control, these cars steer autonomously, following guidance wires embedded in the road. Meanwhile, feel free to read, chat with your companions, or get some work done. Major highway systems could be in place as early as 1975, so we can promise that this technology will be coming very, very soon to a road near you. ■



**McKinsey defines the DNA of Industry 4.0 convergent disruption as the proliferation of big data, adv. analytics, HMI and dig.-to-physical transfers.**

# Autonomous Drones



**McKinsey defines the DNA of Industry 4.0 convergent disruption as the proliferation of big data, adv. analytics, HMI and dig.-to-physical transfers.**

# Market Disruptions

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## Autonomous Cars

- Changing car ownership, MaaS.
- Insurance, maintenance, towing etc.
- Disabled and elderly will have access to mobility.
- Parking practices will change.

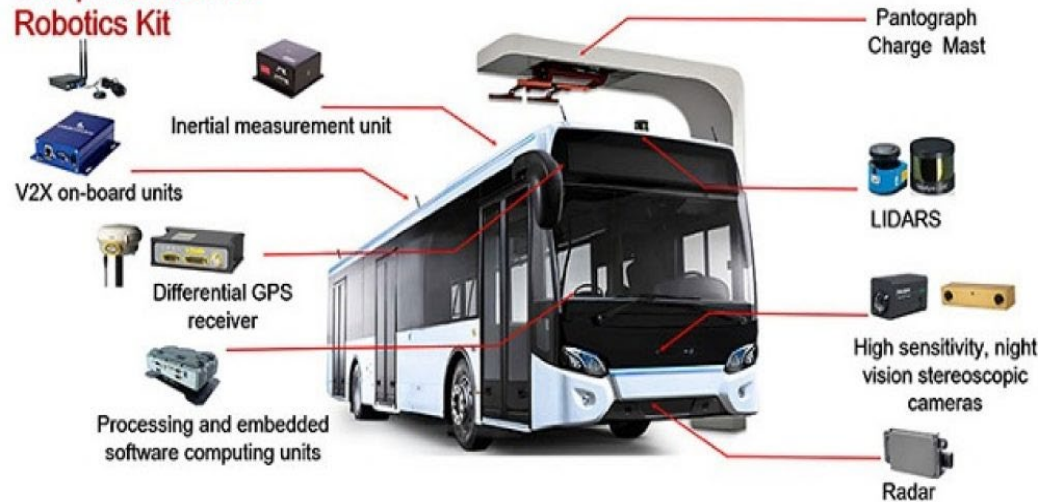
## Autonomous Drones

- Ground delivery vs drone delivery.
  - Air taxis, MaaS.
  - Efficient services such as surveillance, mapping.
  - Airline/helicopter piloting changes.
-



# Public Transport

## Components of AV Robotics Kit



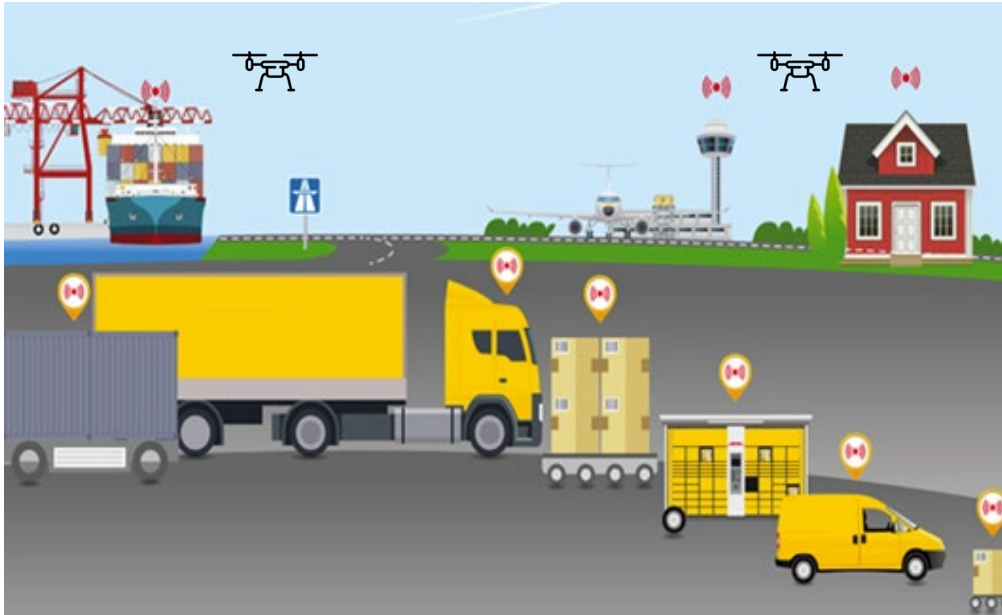
## Potential Impact:

- 24x7 Access
- Reuse of Infrastructure (Utilization)
- On-call Access

## Simplifications:

- Limited Paths
- Managed Intersections and Pedestrians
- Lower Speeds

# Logistics



## Potential Impact:

- Warehouse Operations
- Outdoor Logistics Operations
- Long Haul and Last Mile

## Simplifications:

- Controlled Environments
- Human Leverage (“follow-me” model)

# Planned Communities



## Potential Impact:

- Enable driverless elderly communities
- Increase Safety and Health Simultaneously
- Efficient Architectural Designs

## Simplifications:

- Lower Speeds
- Controlled Environments
- Less Complex Interaction Models

# Agriculture

## Send in the drones

### How a drone tractor works

Iowa-based Kinze Manufacturing Inc. has partnered with Jaybridge Robotics of Massachusetts to develop an autonomous agricultural equipment system it plans to launch in spring 2012. The system is designed to increase productivity, reduce input costs, and operate safely and efficiently. Kinze has not disclosed the final cost to the farmer. The system's components:

A small industrial computer is mounted in the cabin. Electronics allow the computer to drive the tractor and link it with external equipment, like planters or grain bins. An inertial measurement unit gives the system directional awareness. Wireless and cellular networks provide communication between tractor and farmer.

Ag camera: Allows the human supervisor to monitor operations from a remote location.

LIDAR: Emits a laser beam to detect objects without high metal or water content, like a PVC standpipe or a wooden fence post.

Standard automotive radar system: Borrowed from modern adaptive cruise control systems. Good for detecting metal objects and objects with high water content like livestock and people.

Secondary ag camera

Standard GPS system

Real time kinetic (RTK) GPS antenna: Provides accuracy to within 2-4 centimeters on the Earth's surface.

Sources: Jaybridge Robotics; Kinze Manufacturing, Inc.; Capital Press research; Alan Kenaga/Capital Press

#### The "brain"

The software enables everything to work together. Because the computer is not particularly powerful, algorithms written into the program are efficient and application-specific, but general enough to be modified for other uses.

### Potential Impact:

- 24x7 Operation
- Higher Level of Capability (e.g. Fruit Picking Robots)

### Simplifications:

- Lower Speeds
- Less Complex Interaction Models



# Autonomous Car Market Estimates

**Bloomberg Technology** Markets Tech Pursuits Politics Opinion Businessweek

## Driverless-Car Global Market Seen Reaching \$42 Billion by 2025

by Jeff Green

January 8, 2015 – 3:03 PM EST

Vehicles that drive themselves on the freeway or take road in large numbers by 2017 and autonomous cars for the technology by 2025, Boston Consulting Group

Self-driving cars, building on technology already available able to navigate crowded city streets by 2022 and sales by 2035, the firm said today, citing interviews with consumer surveys. Japan and western Europe will progress quickly, its study found.

## Self-driving Cars Will Be \$87 Billion Market by 2030

By Willie D. Jones  
Posted 2 Jun 2014 | 14:00 GMT

By 2035, 12 million fully autonomous units could be sold a year globally, and the market for partially and fully autonomous vehicles is expected to leap from about \$42 billion in 2025 to nearly \$77 billion in 2035.

The market for partially and fully autonomous vehicles is expected to leap to nearly \$77 billion in 2035.

**\$42-\$77 BILLION**

From 2025 to 2035, growth in the market for partially and fully autonomous vehicles will likely reach between \$42 billion and \$77 billion.

**25%**

By 2035, autos with autonomous vehicle features are expected to capture 25% of the new car market.

...test self-driving car demo. The company's fleet of autonomous vehicles give us a window to the future of

**Market estimates vary but several groups estimate the market over \$80 Billion in just under fifteen years**

# Autonomous Car Market Estimates

**WIRED** Waymo's Self-Driving Car Crash in Arizona

BUSINESS CULTURE GEAR IDEAS

AARIAN MARSHALL AND ALEX DAVIES TRANSPORTATION 05.04.18 06:46 PM

## WAYMO'S SELF-DRIVING CAR CRASH IN ARIZONA REVIVES TOUGH QUESTIONS

CAR TECHNOLOGY

## Two Years On, A Father Is Still Fighting Tesla Over Autopilot And His Son's Fatal Crash

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## Tesla driver dies in first fatal crash while using autopilot mode

The autopilot sensors on the Model S failed to distinguish a white tractor-trailer crossing the highway against a bright sky

2025

ADVANCED TRANSPORT

## ONE OF APPLE'S AUTONOMOUS CARS JUST CRASHED

**The Economist** Topics Current edition More

Autonomous vehicles

## A pedestrian has been killed by a self-driving car

*A driverless tragedy*

**CA.GOV** State of California Department of Motor Vehicles

Home Offices Online Services Appointments Driver License

## Report of Traffic Collision Involving an Autonomous Vehicle

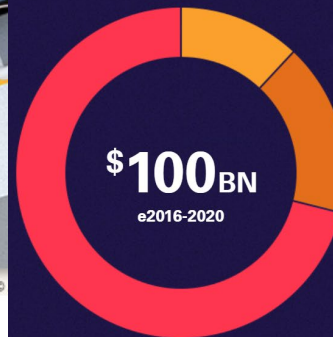
**The New York Times**

## Self-Driving Tesla Was Involved in Fatal Crash, U.S. Says

**Market estimates vary but several groups estimate the market over \$80 Billion in just under fifteen years**

# Autonomous Drone Market Estimates

## Global Autonomous BVLOS Drone Market to Reach \$34.65 Billion by 2029



### THE OPPORTUNITY AHEAD

Between now and 2020, we forecast a \$100 billion market opportunity for drones—helped by growing demand from the commercial and civil government sectors.

Source: Goldman Sachs Research

### Global Autonomous Last Mile Delivery Market

OPPORTUNITIES AND FORECAST, 2021-2030

Global Autonomous Last Mile Delivery Market is projected to reach **\$75.6 billion** by 2030.

Growing at a **CAGR of 23.7%** (2021-2030)

**Market estimates vary but several groups estimate the market over \$40 Billion in just under fifteen years**

# Autonomous Drone Market Estimates

The Washington Post  
Democracy Dies in Darkness

Business

## Biggest obstacle for delivery drones isn't the technology: It's you and me

Anslys | BLOG



Published on November 21, 2019 by [Robert Harwood](#)

[Aerospace and Defense](#), [Electromagnetics](#), [Electronics](#), [Embedded Software](#), [Systems Engineering](#)  
[Aerospace and Defense](#), [Autonomous Vehicles](#), [Drones](#), [Electric Vehicles](#)

### The Challenges to Developing Fully Autonomous Drone Technology

alphr

A situation where it is unclear whether drone deliveries are compatible with existing property law.

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OPINION

## The 5 Most Pressing Problems With Drone Delivery

By [Rob Enderle](#)

Jun 10, 2019 10:08 AM PT

[Print](#)  
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Market estimates vary but several groups estimate the market over \$35 Billion in just under fifteen years



# Research Goal

The Washington Post  
*Democracy Dies in Darkness*

Business

## Biggest obstacle for delivery drones isn't the technology: It's you and me

Global Autonomous Mile Delivery

Ansys | BLOG



Published on November 21, 2019 by Robert Harwood

Aerospace and Defense, Electromagnetics, Electronics, Embedded Software, Systems Engineering  
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OPINION

## The 5 Most Pressing Problems With Drone Delivery

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**Our research goal is focused on building a framework to identify complex rare scenarios for AV Validation**

# Current Efforts in AV Validation

- **Real World Testing**
  - Low probability tests are difficult to produce
  - Extremely slow and costly
- **Test Tracks & Labs**
  - Recreates various situations
  - Can't be the sole solution for scenario analysis
- **Image Dataset Based Testing**
  - Datasets of images for assisted control
  - Still slow and costly
- **Simulation Based Testing**
  - Current solutions are not progressive



NY Times - 1991

**All current verification efforts are slow, costly, hard to repeat and not progressive**

# Challenges

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## Autonomous Cars

- 2D environment
- Established regulations
- Congested operation domain
- More prescriptive (roads, signs etc.)

## Autonomous Drones

- 3D environment
- Shifting regulations
- Challenging last 10 feet of delivery
- Possible high number of adversarial actors

**Autonomous technology is applicable in both domains with similar challenges and different constraints**

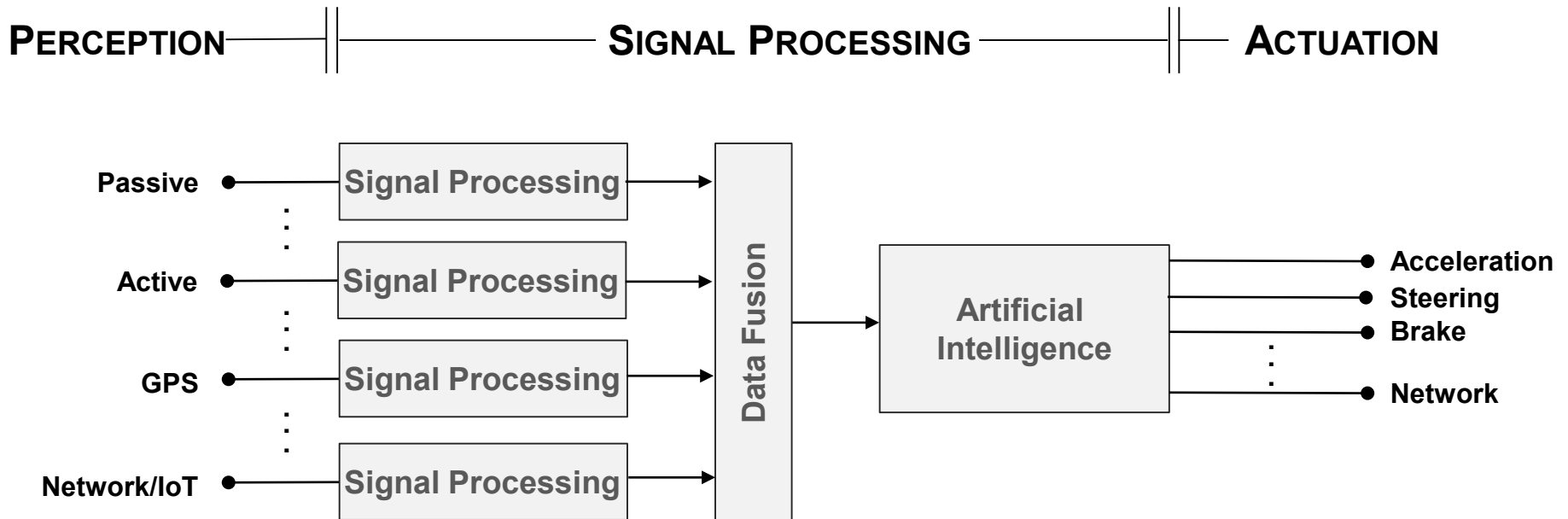
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# Outline

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- About Me
  - Rise of Autonomy and Challenges
  - **Validation Framework**
  - **Other Research Themes**
  - **Summary**
-

# Technology Core



- Hard-wired **vehicles operated by people** replaced by software-defined & networked **computers operated by intelligent agents**
- Fundamental technology is a traditional **networked sensor and signal processing chain with a decision support system**

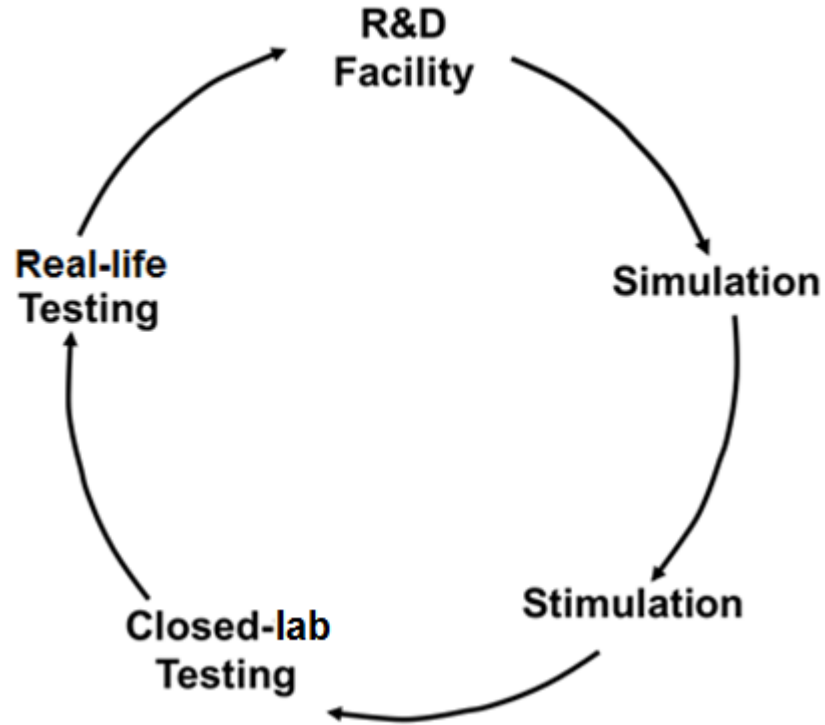
# Critical Issues

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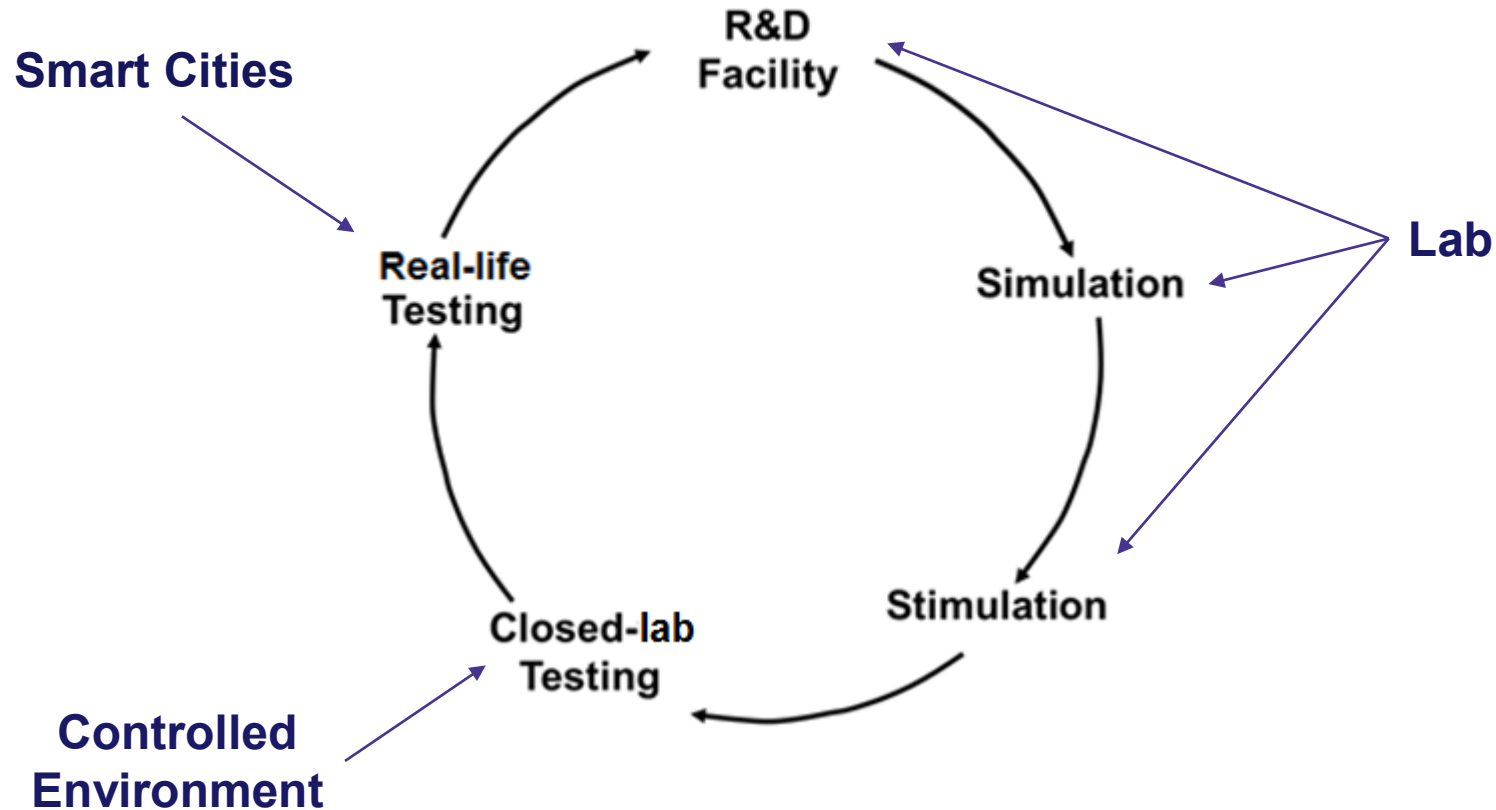
- **Conceptual Model:** What are the conceptual models for decision making and perception stages?
  - **Test Regime:** What is the test regime that can build confidence for the operation of the AV?
  - **Completeness:** How do we understand the state space sufficiently?
  - **Accumulative Learning:** How do we know the next version of the AV is safer?
-

# AV Testing Solution

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# AV Testing Solution



**Our research aims to create a full framework to conduct research, development and testing of AVs**



# Similarities to Hardware V&V

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- Semiconductor chips are composed of **complex components**
  - Most semiconductor chips can be simulated in the low kilo-hertz **range** while run in giga-hertz range
  - There is a need to compress long learning cycle into a **reasonable development cycle**
  - There is a need for **robustness to environmental conditions**
  - There is a need for **completeness and accumulated learning**
-

# Solutions from Hardware V&V

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- Use of **abstraction** to decompose the problem
- Development of various **abstraction levels** (transistor, gate, RTL, micro-architecture, architecture, network)
- At the highest level:
  - Formal verification
  - Constrained-random test generation
  - Real-world test injection
  - Coverage analysis

**Our solution aims to use the powerful methods of hardware and software V&V for Autonomous Vehicles**

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# Scenario Testing Solution

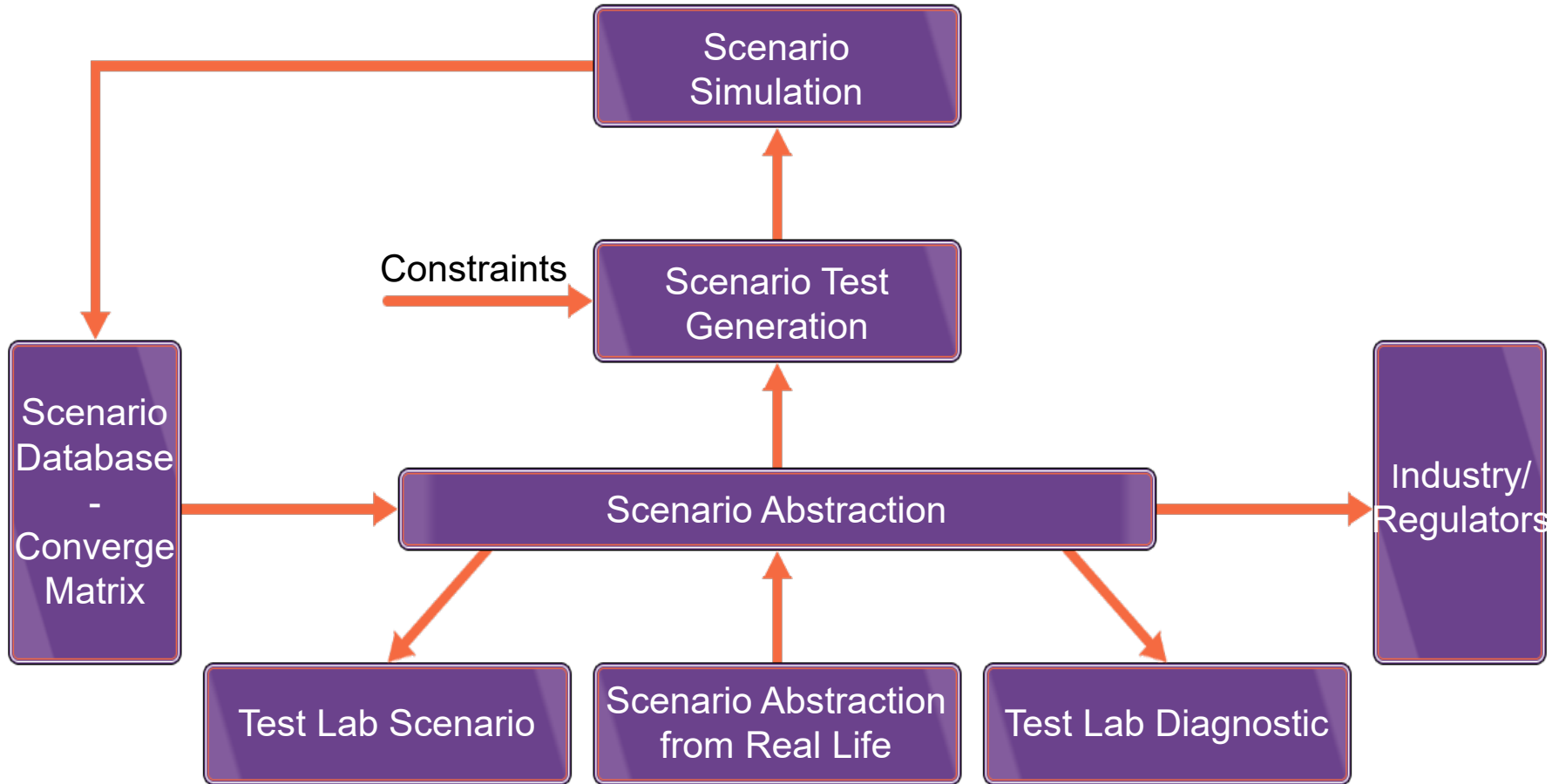
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- **Characterization**
  - Decompose data sets from physical world into atomic blocks
- **Scenario generation**
  - Build virtual models using atomic elements
- **Coverage analysis**
  - Track cross-product cases
- **Certification**
  - Based on coverage completion

**The solution is focused on the  
Decision Making of Autonomous Vehicles**

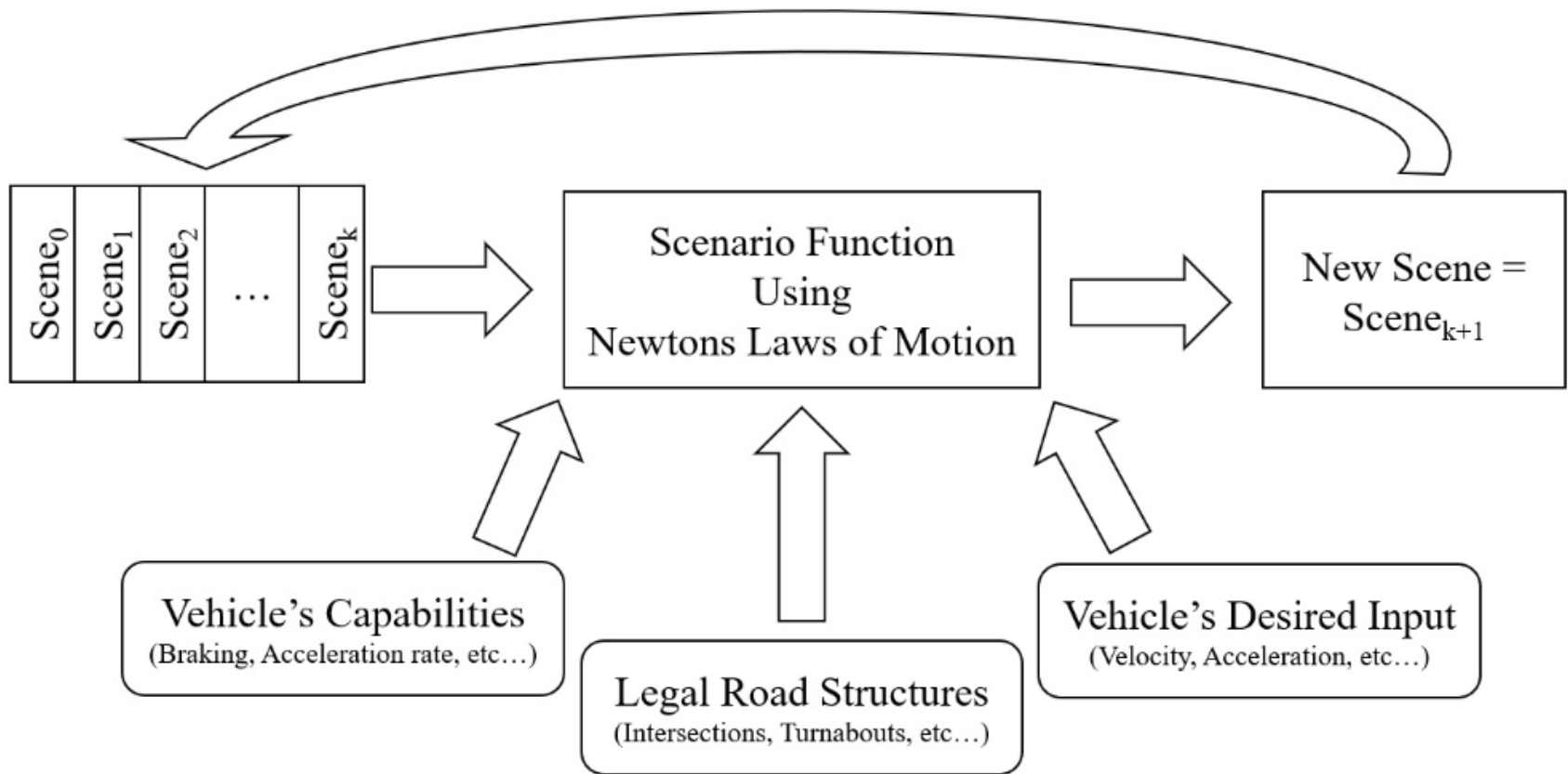
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# Scenario Abstraction



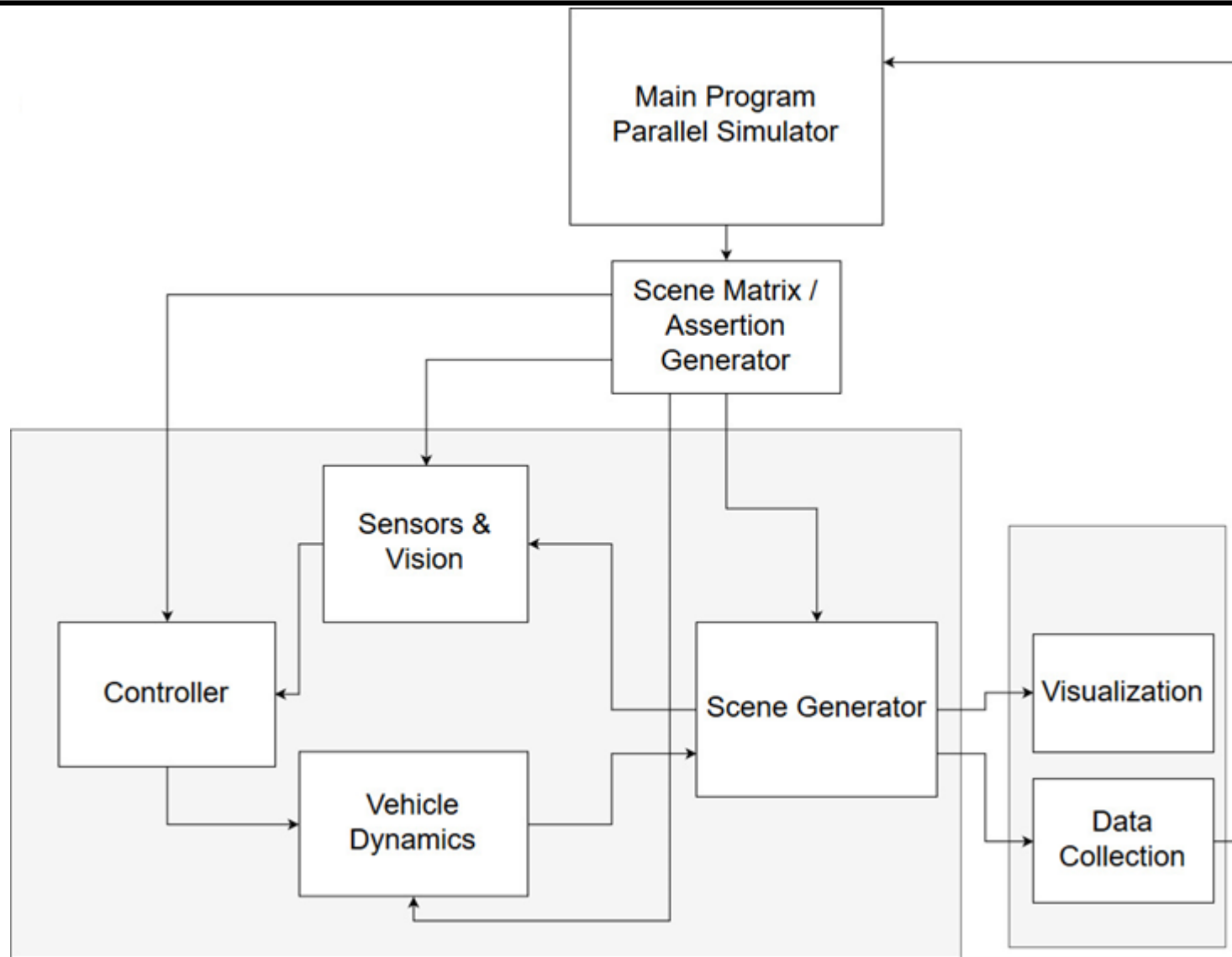
**The framework serves as a ground truth for testing other sources of error such as environmental conditions or sensor failures**

# Formulation of Test Scenarios



**Assertion functionality on top of this inner core provides the concepts of good/bad or pass/fail**

# Simulation Architecture



# Implementation

- Semantic language is used to define scenarios
- Actors, environment are created/validated
- Low fidelity simulator is the first step for implementation

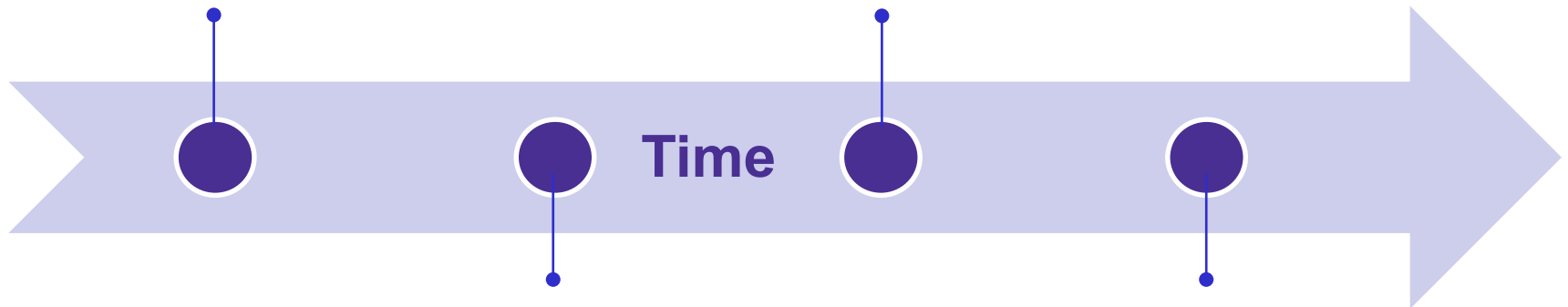
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2	1.0000000e+00	8.0000000e+01	3.0000000e+00	1.0000000e+00	0.0000000e+00	2.4587200e+01	2.0000000e+02	8.9486000e-03	-1.3291000e-02	
3	1.0000000e+00	1.2000000e+02	1.0000000e+00	1.0000000e+00	1.0000000e+00	1.7881600e+01	2.0000000e+02	-5.0939000e-03	-1.2988000e-02	
4	1.0000000e+00	1.1000000e+02	1.0000000e+00	1.0000000e+00	1.0000000e+00	3.1292800e+01	1.0100000e+02	-1.1618000e-02	-1.6683000e-02	
5	1.0000000e+00	1.5000000e+02	5.0000000e+00	1.0000000e+00	1.0000000e+00	3.3528000e+01	2.0000000e+00	2.0745000e-02	-7.3204000e-03	
6	1.0000000e+00	1.3000000e+02	3.0000000e+00	1.0000000e+00	0.0000000e+00	1.7881600e+01	2.1000000e+01	-5.6088000e-03	-1.8636000e-03	
7	1.0000000e+00	1.0000000e+02	3.0000000e+00	1.0000000e+00	1.0000000e+00	2.6822400e+01	1.2000000e+01	-1.2991000e-02	-2.7227000e-03	
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11										
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13	1.0000000e+00	3.0000000e+00	2.0000000e+00	0.0000000e+00	8.0000000e+00	3.0000000e+00	1.0000000e+01	8.4000000e-01	1.0000000e+00	4.9000000e-01
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15	2.0000000e+00	3.0000000e+00	2.0000000e+00	0.0000000e+00	1.0000000e+00	5.0000000e+00	1.0000000e+01	7.9000000e-01	0.0000000e+00	4.6000000e-01
16	1.0000000e+00	1.0000000e+00	1.0000000e+00	3.0000000e+00	7.0000000e+00	2.0000000e+00	5.0000000e+00	5.0000000e-02	0.0000000e+00	7.4000000e-01
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20	2.0000000e+00	1.0000000e+00	2.0000000e+00	2.0000000e+00	1.0000000e+01	4.0000000e+00	3.0000000e+00	2.5000000e-01	1.0000000e+00	9.7000000e-01
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[View Streaming Video](#)

# AV Testing Framework Roadmap

**Simulation &  
Scenario Testing**

**AV Testing**



**Hardware in the  
Loop Testing**

**Individual  
Sensor Testing**

**Next: Automatic test pattern generation to find edge cases,  
collaboration with environmental and HiL Simulators**



# Outline

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# Transportation Operating System

- Transportation System is inefficient
- Utilization of **Market Economics** and Network Ideas


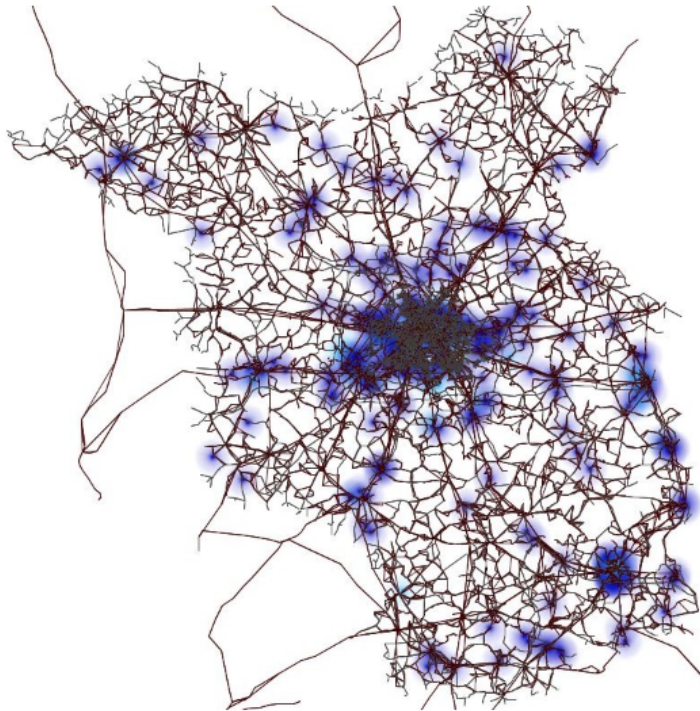


What if we could dynamically use the transportation system resources?



# Incentive Mechanisms for Mobile Crowdsensing

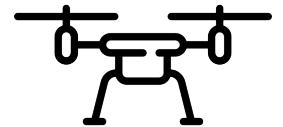
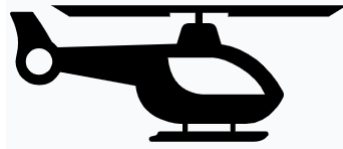
- **Spatial and temporal coverage** for sampling in a target area and isolated sub-regions is important
- An **incentive mechanism** that dynamically assigns compensation for data collection in the sub-regions



How can we incentivize users of ITS for coverage?

# Cooperation of AVs with Human Operators

- Humans have operating languages, AVs need it as well



# Outline

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- About Me and Florida Poly
  - Rise of Autonomy and Challenges
  - Florida Poly Solution
  - Florida Poly Research Themes
  - **Summary**
-

# Thank You!

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**M. Ilhan Akbas, PhD**

**Assistant Professor of Electrical and Computer Engineering  
Embry-Riddle Aeronautical University**

- [akbas@erau.edu](mailto:akbas@erau.edu)
  - <https://sites.google.com/site/miakbas/>
  - <https://www.linkedin.com/in/miakbas/>
-