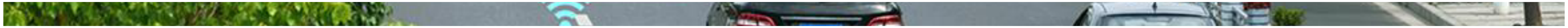
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

Progress on Systems Interaction in Automated Vehicles



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Contributions

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- Mac McCall – Kevin Kefauver

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NIST – National Institute of Standards and Technology, U.S. Department of Commerce

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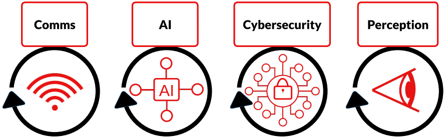
Outline

Title: *Progress on Systems Interaction in Automated Vehicles.*

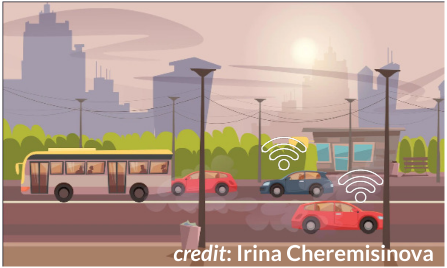
- In 2022, NIST held the Standards and Performance Metrics for On-Road Autonomous Vehicles Workshop.
- The workshop identified several key areas (systems) in which NIST could have an impact.
  - Artificial Intelligence (AI).
  - Communication.
  - Cybersecurity.
  - Perception.

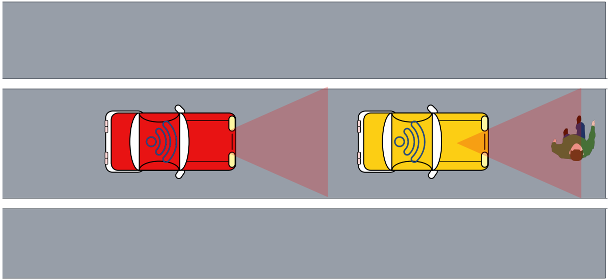
Testbeds for Automated Vehicles (AVs) can be categorized into two main types.

1. Individual system testing.
   - Testing specific components or systems of the vehicle in isolation.
     - e.g., evaluating sensor suite.



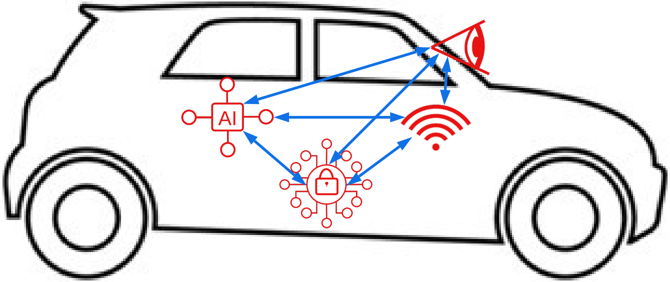
2. Full vehicle testing.
   Evaluation of AVs is performed in the environment.



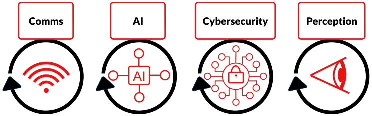


- In this scenario, it would be useful to study how the AV systems interact with each other to be able to answer crucial questions such as:
  - What happens if the communications between the front and the back vehicles are delayed?
  - What happens if a cyber event disrupts perception?
  - How would the interactions between some of these AV systems impact the overall performance of both vehicles?

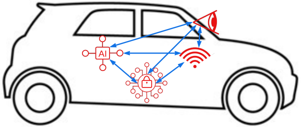
NIST aims to investigate a systems interaction testbed and evaluation framework that bridges the gap between individual system testing and full vehicle testing.



1. Individual system testing.
   - Testing specific components or systems of the vehicle in isolation.
     - Example: Evaluating sensor suite and communication layers.



2. **Systems interaction testbed and evaluation framework.**
   - The interactions between AV systems are tested.



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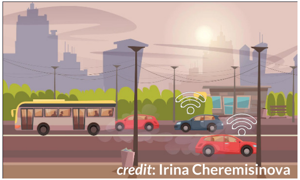


Standards and Performance Metrics for On-Road Autonomous Vehicles – March 8–9 2022.

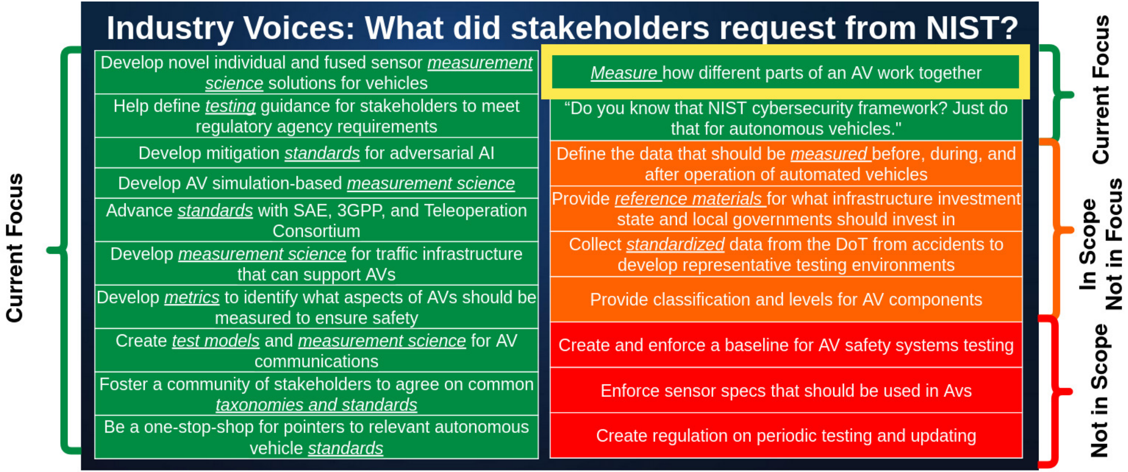
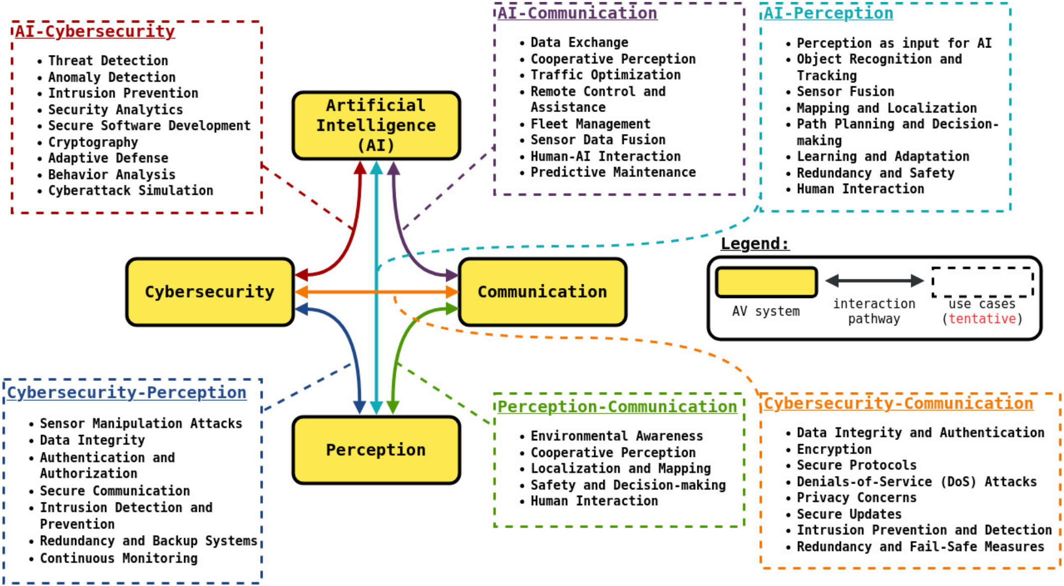


Figure: Stakeholders have identified the importance of measuring interactions between systems that affect overall vehicle performance.

Impact on Quality Attributes

- *Enhanced Safety* – Identifying potential conflicts or weaknesses in the interactions can help implement robust safety mechanisms.
- *Improved Performance* – e.g., studying the interactions between AI and perception systems can enhance object recognition.
- *Reliability* – Understanding the interactions between these systems can help identify potential failure points and vulnerabilities.
- *Scalability* – Studying these interactions helps ensure they can operate safely and reliably in a variety of environments and conditions.

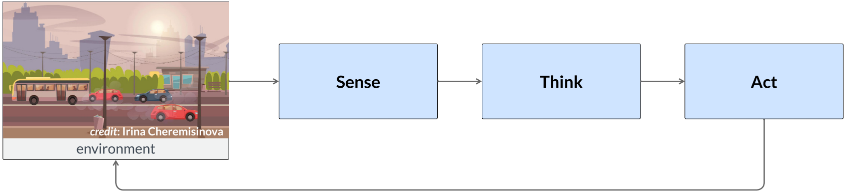

AI-Cybersecurity
• Threat Detection
• Anomaly Detection
• Intrusion Prevention
• Security Analytics
• Secure Software Development
• Cryptography
• Adaptive Defense
• Behavior Analysis
• Cyberattack Simulation
Artificial Intelligence (AI)
AI-Communication
• Data Exchange
• Cooperative Perception
• Traffic Optimization
• Remote Control and Assistance
• Fleet Management
• Sensor Data Fusion
• Human-AI Interaction
• Predictive Maintenance
AI-Perception
• Perception as input for AI
• Object Recognition and Tracking
• Sensor Fusion
• Mapping and Localization
• Path Planning and Decision-making
• Learning and Adaptation
• Redundancy and Safety
• Human Interaction
Cybersecurity
Communication
Legend:
AV system
interaction pathway
use cases (tentative)
Cybersecurity-Perception
• Sensor Manipulation Attacks
• Data Integrity
• Authentication and Authorization
• Secure Communication
• Intrusion Detection and Prevention
• Redundancy and Backup Systems
• Continuous Monitoring
Perception
Perception-Communication
• Environmental Awareness
• Cooperative Perception
• Localization and Mapping
• Safety and Decision-making
• Human Interaction
Cybersecurity-Communication
• Data Integrity and Authentication
• Encryption
• Secure Protocols
• Denials-of-Service (DoS) Attacks
• Privacy Concerns
• Secure Updates
• Intrusion Prevention and Detection
• Redundancy and Fail-Safe Measures

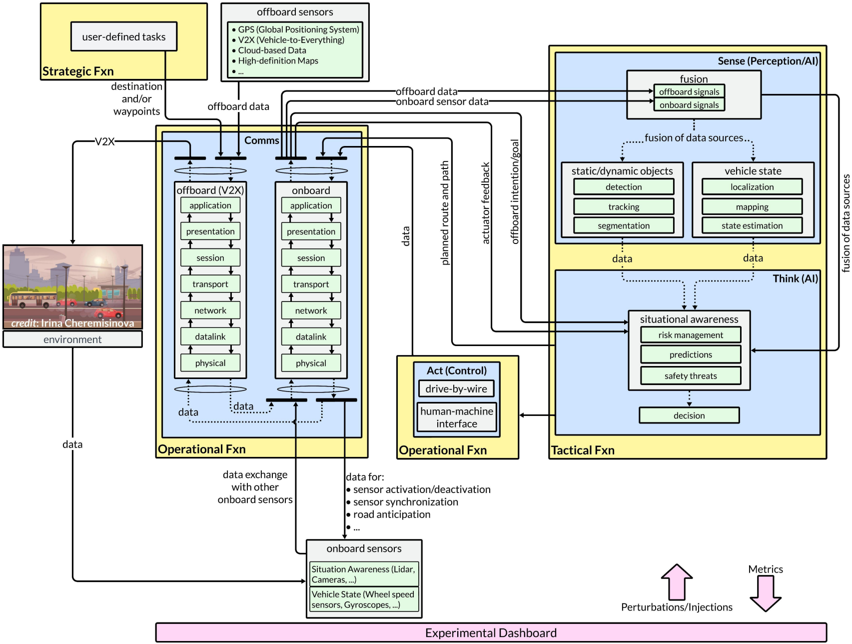
- *Testbed* – Useful to stakeholders to transition individual system-level testing to overall vehicle performance.
  1. *Design* – Develop an AV systems interaction architecture which provides a structured approach to managing and facilitating communication and collaboration among different AV systems.
  2. *Implementation* – Use the architecture to implement on-road scenarios.
  3. *Evaluation* – Develop and use the Automated Driving Systems Interaction Evaluation (ADSIE) framework to evaluate the performance of AVs in on-road scenarios.

1. Design

Sense-Think-Act Paradigm

- *Sense* – This step involves perceiving and collecting data from the environment using various sensors.
- *Think* – The collected data is processed and interpreted to make informed decisions based on predefined rules, machine learning models, or other algorithms.
- *Act* – Actions (steering, accelerating, or braking) are taken to interact with the environment.




user-defined tasks
Strategic Fxn
offboard sensors
• GPS (Global Positioning System)
• V2X (Vehicle-to-Everything)
• Cloud-based Data
• High-definition Maps
• ...
destination and/or waypoints
offboard data
V2X
Comms
offboard (V2X)
onboard
application
presentation
session
transport
network
datalink
physical
data
data
Operational Fxn
credit: Irina Cheremisinova
environment
data
offboard data
onboard sensor data
data
planned route and path
actuator feedback
offboard intention/goal
Sense (Perception/AI)
fusion
offboard signals
onboard signals
fusion of data sources
static/dynamic objects
detection
tracking
segmentation
vehicle state
localization
mapping
state estimation
data
data
Think (AI)
situational awareness
risk management
predictions
safety threats
decision
fusion of data sources
Act (Control)
drive-by-wire
human-machine interface
Operational Fxn
Tactical Fxn
data exchange with other onboard sensors
data for:
• sensor activation/deactivation
• sensor synchronization
• road anticipation
• ...
onboard sensors
Situation Awareness (Lidar, Cameras, ...)
Vehicle State (Wheel speed sensors, Gyroscopes, ...)
Metrics
Perturbations/Injections
Experimental Dashboard

2. Implementation

Simulation and Physical Testbeds

The testbed is expected to be implemented in simulation and on a physical vehicle.

1. *Simulation-based testbed* – Translate the structural concepts of the AV systems interaction architecture into simulation.
   - Requirements (29 were identified):
     - Real time to support hardware-in-the-loop.
     - Ability to introduce perturbations/injections at different levels in the architecture.
     - Create scenarios with minimum time and effort.
     - Physics based with realistic environments (infrastructures, vehicles, and pedestrians).
     - Has some ADS features.
     - ...
2. *Physical testbed* – Will be put into action following the simulation testbed (next step).
   - Adapt simulation models.
   - Calibration and sensor fusion.
   - Testing procedures.
   - Test execution.
   - Data analysis and comparison.
   - ...

Tools* for the Simulation Testbed

Autoware - https://autoware.org

- Open-source software stack used for research and development of autonomous vehicle systems. Designed to run in simulation and on actual vehicles.

CARLA (Car Learning to Act) – https://carla.org

- Physics-based and open-source simulator for autonomous driving research.
- Not intended for running on physical vehicles but is used for simulating and testing autonomous driving algorithms and vehicles in a virtual environment.

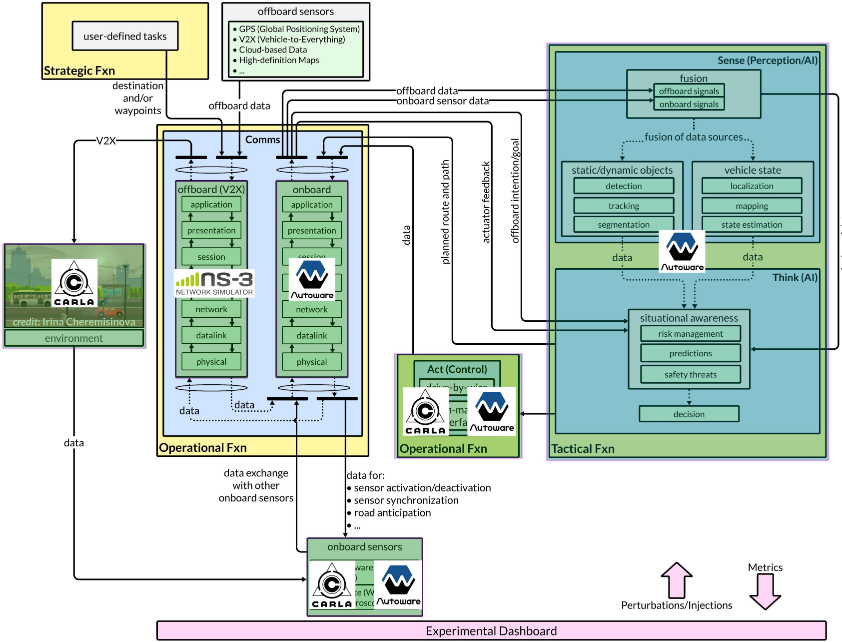
ns-3 – https://www.nsnam.org/

- Open-source discrete-event network simulator used for research and development in computer networks and communication systems.

ROS (Robot Operating System) – https://www.ros.org

- Open-source framework based on a publish-subscribe messaging system (mainly used for robotics software).

*Certain commercial products or company names are identified here to describe the effort. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the products or names identified are necessarily the best available for the purpose.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• ...
onboard sensors
Perturbations/Injections
Metrics
Experimental Dashboard

Reveal Driving Scenario

1. Front, Center, and Rear (Ego) vehicles driving in the far left lane on the highway.
2. Front vehicle suddenly stops in its lane (malfunction).
3. Center vehicle passes Front vehicle.
4. Rear vehicle initiates Automatic Emergency Braking (AEB).

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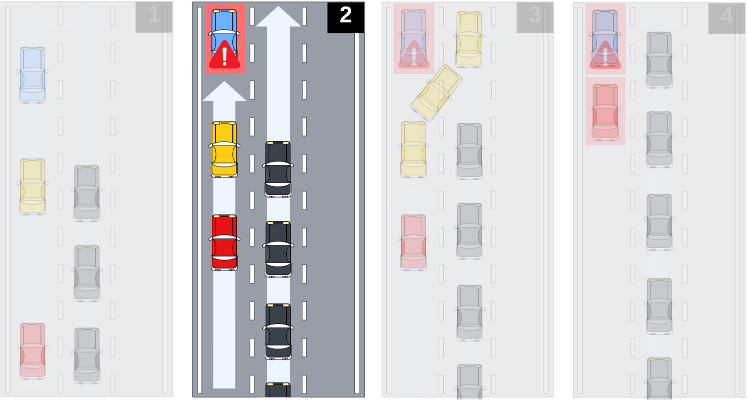

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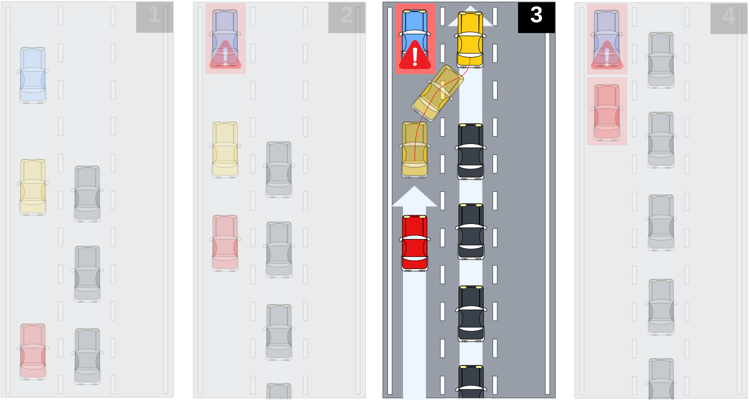

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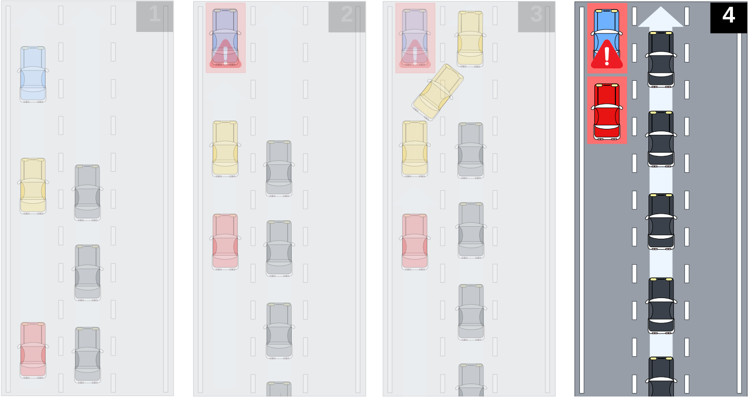


Simulated Reveal Driving Scenario

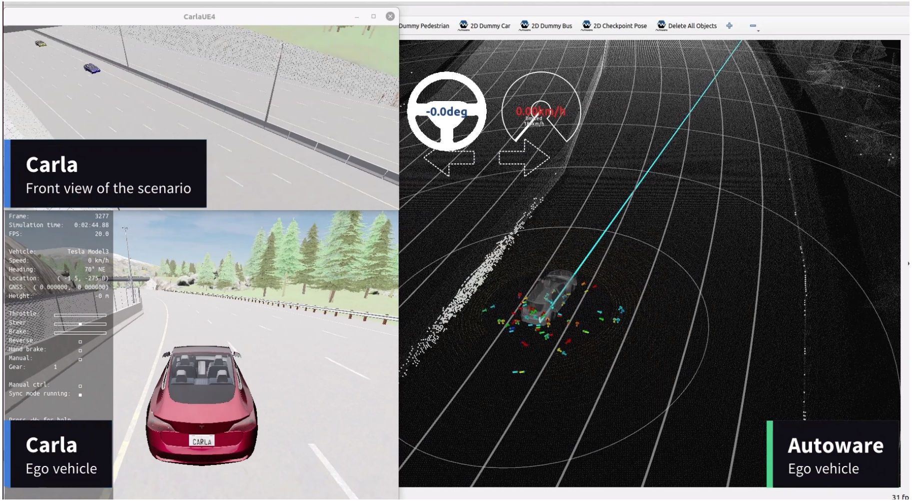


Figure: Reveal scenario with Carla, Autoware, and ROS.

3. Evaluation

ADSIE Framework

- NIST proposes the Automated Driving Systems Interaction Evaluation (ADSIE) framework.
  - Enables stakeholders to create, evaluate, and implement testing scenarios aimed at capturing the system interaction performance of automated driving features.
  - Aims to accelerate the manufacturing and adoption of automated driving technologies.
- The ADSIE framework consists of 6 pillars:

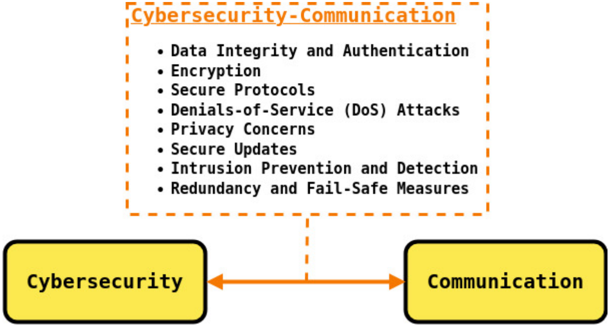
Systems	Scenario	Metrics	Behavior Assessment	Perturbations	Uncertainties
Which AV systems are currently being examined?	What are we exposing the AV to?	What are we measuring?	Which behavior(s) are we assessing in the scenario?	What are we stressing?	What uncertainties are propagated?

Approach for Systems Interaction Evaluation

1. Select an interaction pathway.
2. Select a use case.
3. Identify one of the outcomes for the use case.
4. Implement the use case.
5. Evaluate the performance of the AV.

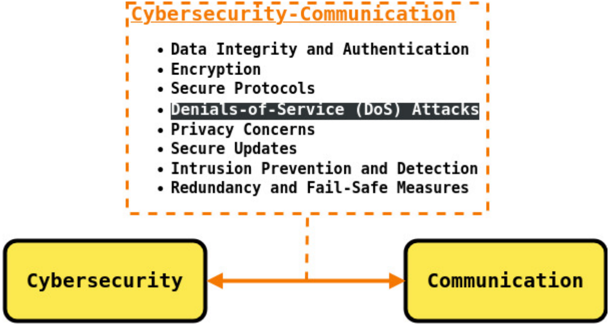
1. Select an Interaction Pathway

- **Example**: Cybersecurity–Communication pathway.



2. Select a Use Case

- **Example**: Denial-of-Service (DoS) Attacks.
  - An attacker floods the network with excessive traffic.
  - Such attacks could disrupt communication between vehicles or between a vehicle and infrastructure.
  - Result: Affect the vehicle's ability to operate safely.

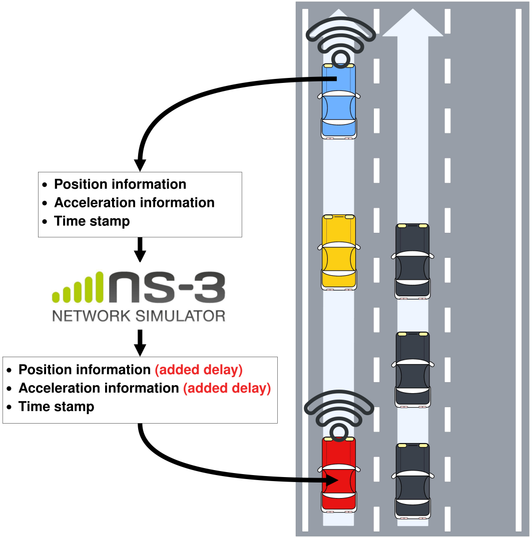


3. Identify One of the Outcomes for the Use Case

- **Example**: Latency
  - DoS attacks overwhelm a target system with a flood of traffic.
  - The target system becomes slow or unresponsive.
  - The increased traffic and the effort to mitigate the attack can lead to latency.

4. Implement the Use Case

- **Example**: Use ns-3 to introduce additional delays in offboard communications.
  - Front vehicle continuously sends its current position, acceleration, and a time stamp to ns-3 server.
  - ns-3 server sends this information to Rear vehicle with an additional delay (ms) for the position and the acceleration.
  - Rear vehicle initiates Electronic Emergency Brake Lights (EEBL) as soon as Front vehicle decelerates.
  - Rear vehicle comes to a full stop in its lane.

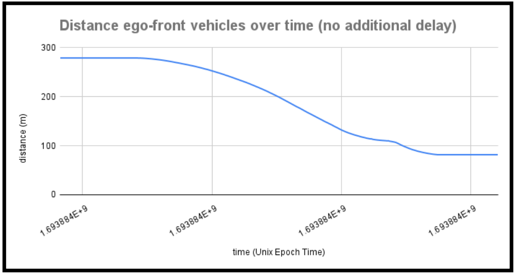


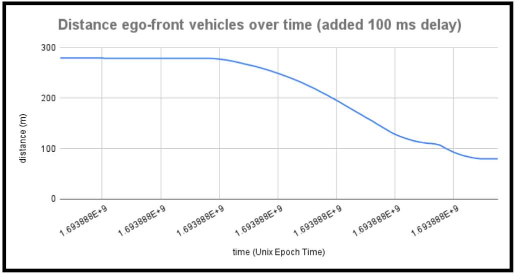
5. Evaluate the AV Performance

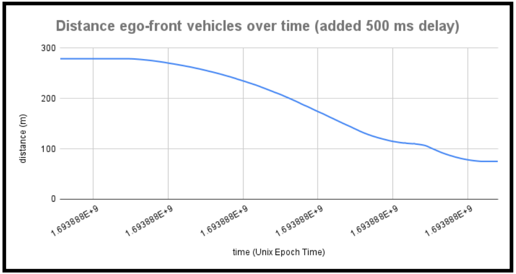
Apply the ADSIE framework to the AV performance evaluation.

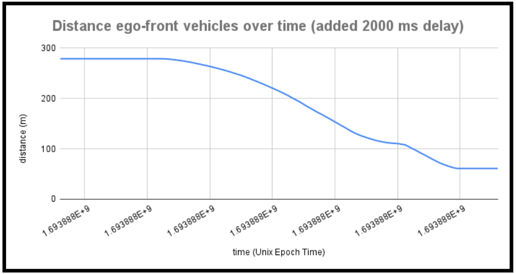
1. *Systems*
   - Cybersecurity and Communication.
2. *Scenario*
   - In this scenario, three vehicles (Front, Center, and Rear) are driving in the far left lane on a highway. Front vehicle stops in its lane due to a malfunction. Center vehicle swerves to the right lane to avoid Front vehicle. Rear vehicle initiates EEBL as soon as Front vehicle decelerates.
3. *Metrics*
   - Distance between Rear (ego) and Front vehicles.
4. *Behavior Assessment*
   - Obstacle avoidance from EEBL.
5. *Perturbations*
   - Additional delays through ns-3 for V2V.
6. *Uncertainties*
   - V2V.

Final distance between ego and front vehicles









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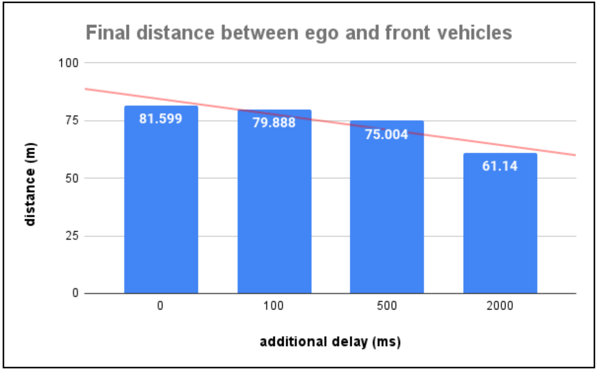

- NIST is working with VTTI to develop a roadmap to a measurement process for AV and ADS performance as it relates to safety from simulation-based to physical testbeds.

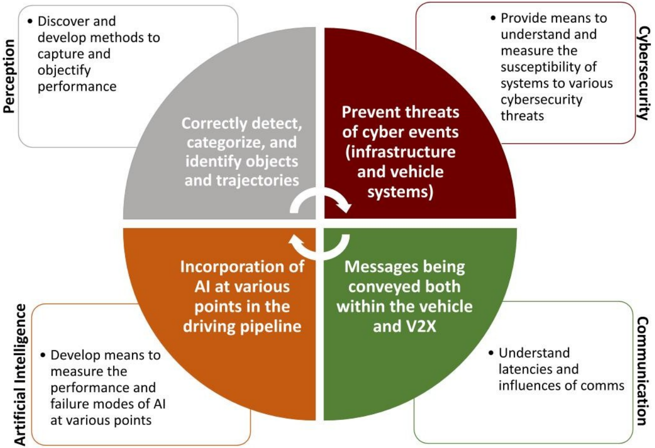

Figure: Roadmap development (credit: Virginia Tech Transportation Institute (VTTI)).

- *Perception* – Static testing (range performance of sensors due to sensor degradation) and dynamic testing (evaluate the localization performance in cases of sensor degradation and GPS denial).
- *AI* – Validate the initial AI test methods.

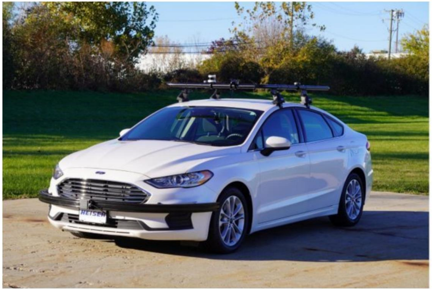

Figure: Ford Fusion 2020 Hybrid† (credit: https://www.dataspeedinc.com).

†Commercial equipment and materials may be identified to specify certain procedures. In no case does such identification imply recommendation or endorsement by the NIST, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

- *Problem Statement*
  - Current testbeds for AVs focus on individual system testing and full vehicle testing.
  - NIST aims to investigate a systems interaction testbed and evaluation framework that bridges the gap between individual system testing and full vehicle testing.
- *Current Progress*
  - Identified interaction pathways and use cases between AI, cybersecurity, communications, and perception.
  - Designed and AV systems interaction architecture to manage and facilitate communication and collaboration among the AV systems.
  - Implemented on-road driving scenarios in simulation.
  - Evaluated the performance of AVs with the ADSIE framework.
- *Next Steps*
  - Revise the interaction use cases.
  - Evaluate the performance of AVs with different interaction use cases.
  - Allow stakeholders to leverage NIST resources for testing and evaluation.
  - Start work on physical testbeds: Work with VTTI on the roadmap and perform various testings with the development mule.

Questions?