



# The Future Begins Here: ADS/IOO Collaborative Framework

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U.S. Department of Transportation  
**Federal Highway Administration**

# Disclaimer

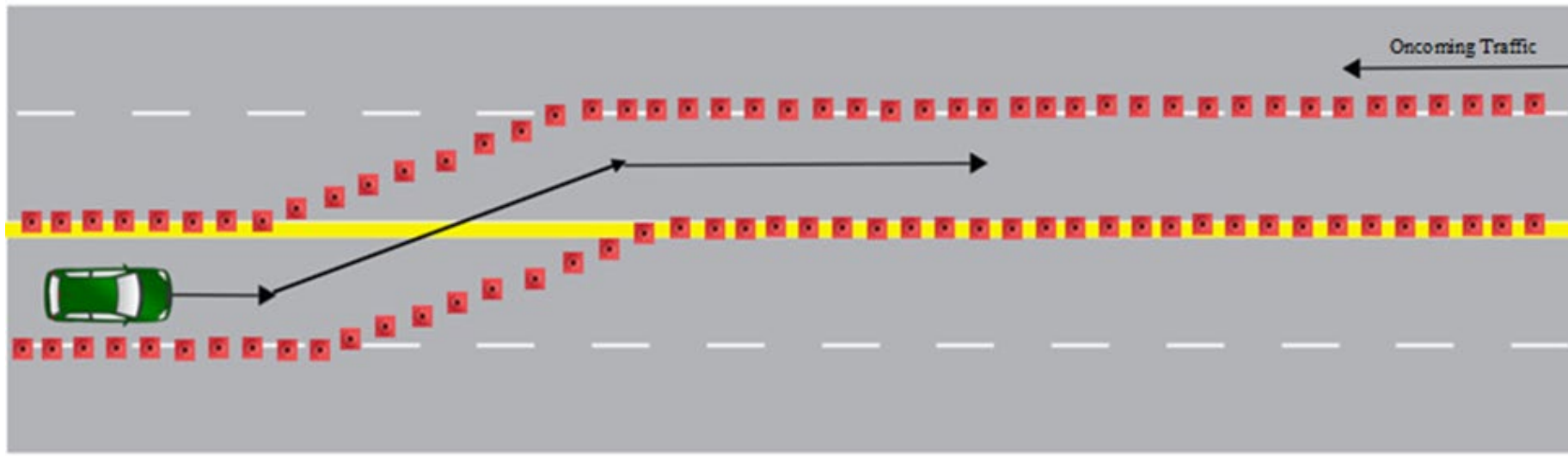
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# Agenda

- History/Purpose
- Framework Introduction and Discussion
- Collaborative Taxonomy
- Success Stories
- Q&A/Discussion

# Work Zones: A Common Sight Across the U.S.



Source: FHWA

- Most drivers will have no trouble steering through the lane shift without hitting or crossing the barriers.
- Is the same true for vehicles equipped with Automated Driving Systems (ADS)?
  - What about with nonorange barrels, faded lane markings, adverse weather, or low lighting?
  - How can ADS testing impart a higher level of public confidence in driverless vehicles?

# Collaboration Adds Diverse, Complementary Perspectives

## ADS Developers

- View a system of external sensory inputs
- Speak a language related to software engineering
- Support an iterative testing model

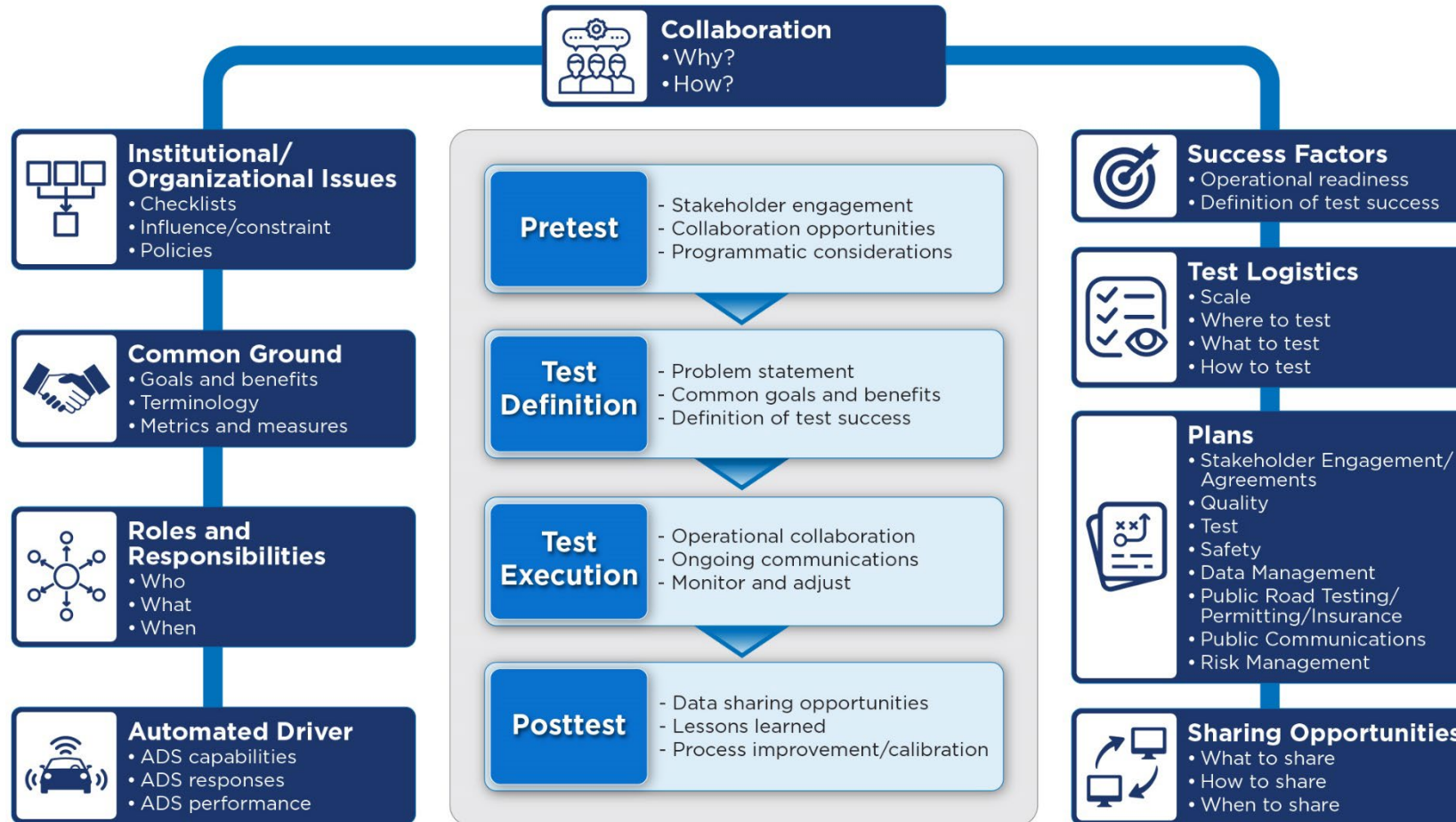
## Infrastructure Owner/Operators (IOOs)

- View a system of safety rules and regulations
- Speak a language related to the Department of Transportation
- Support a comprehensive testing model

### **Both aspire to see safe and efficient deployment of ADS!**

- Likelihood of success is contingent on productive industrywide collaboration.
- The Federal Highway Administration (FHWA) has recognized that:
  - A. There is no set standard on how to test and evaluate ADS technology properly.
  - B. Collaboration between ADS and roadway stakeholders is not adequate.

# Collaborative Research Framework for ADS Developers and IOOs



Source: FHWA

# “The Framework’s” Objectives

- Develop a **collaborative** testing and evaluation framework for ADS technology and the roadway environment.
- Create a **safe** transportation network that is inclusive of ADS-equipped vehicles.

## KEY ITEMS

- Foster Collaboration
- Understand Capabilities
- Enable Deployment

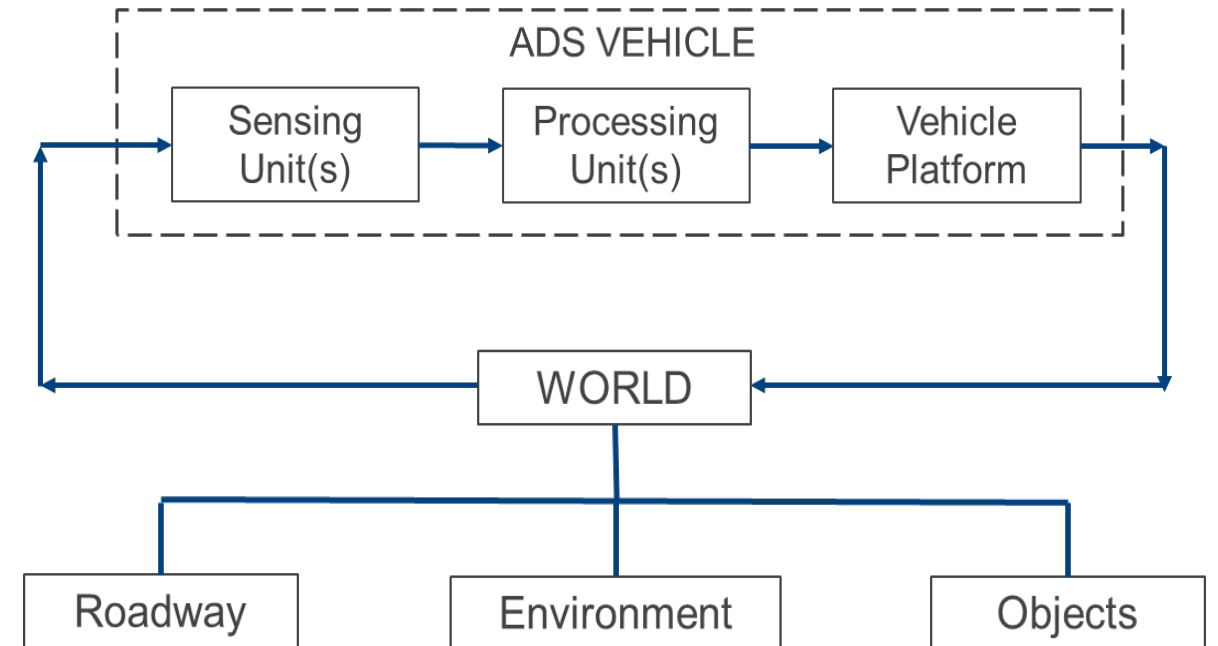
# Framework Development

- This Framework was developed with extensive **engagement** and input from both ADS and Roadway stakeholders.
- Stakeholder engagement included document/concept reviews, webinars, and 1:1 interviews, which allowed the project team to get a broad **perspective** on:
  - Ways to foster collaboration
  - Concerns and needs during ADS and roadway infrastructure testing
  - Essential elements in collaborative ADS testing and evaluation



# Framework Language and Taxonomy

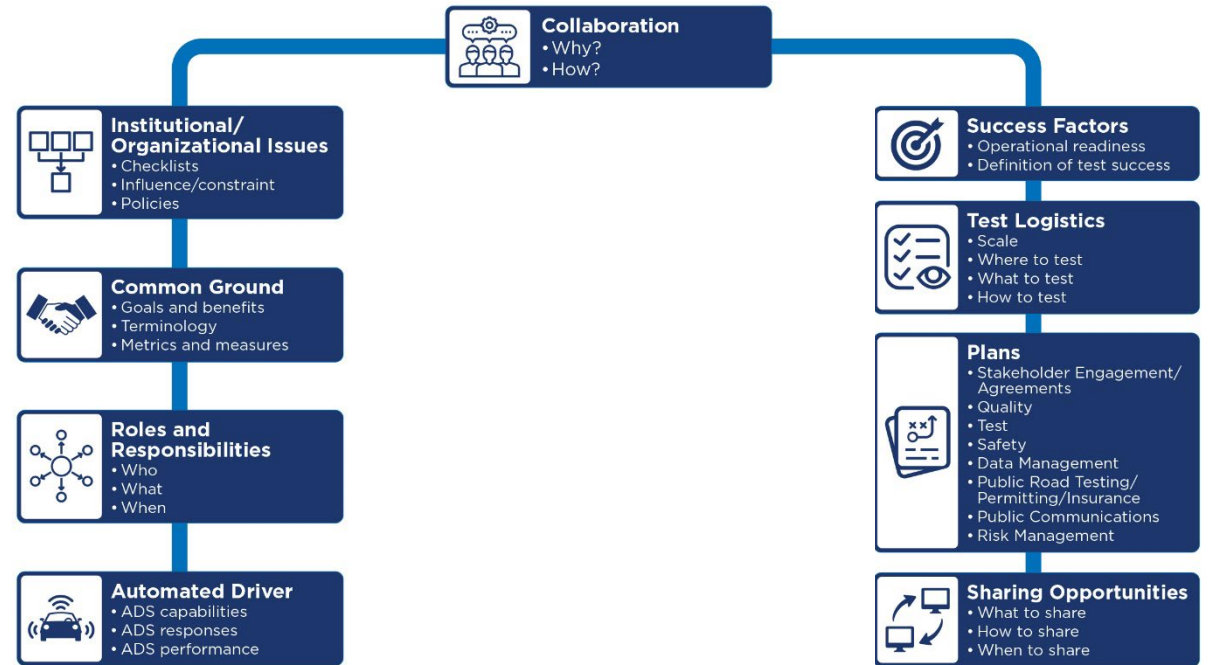
- Facilitates common ground by creating a taxonomy for collaboration:
  - Compatible with SAE J3016\_20104
- Addresses interaction between ADS Vehicles and the surrounding World



Source: FHWA

# The Framework

- The Framework addresses nine **over-arching themes** that represent the key elements of the framework.
- These overarching elements are applied to the different **test phases** along with contextual examples and real-world lessons learned.



Source: FHWA

# Overarching Themes

- The nine overarching aspects represent the key elements of the Framework.



Source: FHWA

## OVERARCHING THEMES

- Collaboration
- Institutional/Organizational Issues
- Common Ground
- Roles and Responsibilities
- A New Driver
- Success Factors
- Test Logistics
- Plans
- Sharing Opportunities



Source: FHWA

## Collaboration

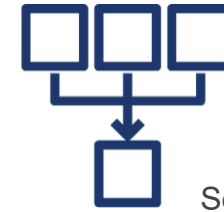
- There are many reasons why collaboration between ADS and IOO stakeholders is **critical for successful testing and evaluation.**
- One prominent reason is that stakeholder collaboration allows for early detection and resolution of ADS issues related to technical, organization, and strategic test implementations.



Source: FHWA

## Common Ground

- Common Ground refers to creating a common or a **shared working environment** so that ADS and IOO stakeholders fully understand each other.
- There are three key components of Common Ground:
  - Common goals and benefits
  - Common terminology
  - Common metrics and measures



Source: FHWA

## Institutional/Organizational Issues

- Since ADS is a relatively new and evolving technology, testing and evaluation will face **challenges** from multiple fronts.
- Having organizational experts from both the ADS and IOO organizations participate early and throughout the test phases will greatly aid in navigating challenges.



Source: FHWA

## A New Driver

- The new driver of tomorrow will be the **vehicle**.
- Successful testing and operation of ADS-equipped vehicles will address how these new drivers:
  - Operate
  - Perform
  - React
  - Adjust



Source: FHWA

## Roles and Responsibilities

- In the process of ADS/Roadway testing and evaluation, it is important to **identify** who from the various organizations needs to participate, what roles within the organizations are needed, and when and in which phases they are needed.
- Some participants may be involved in only one phase, while others may be essential to all phases.



Source: FHWA

## Test Logistics

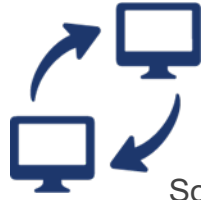
- Test logistics refers to **where** to test, **what** to test, and **how** to test.
- This includes development of test scenarios, testing methodologies, and test environment.



Source: FHWA

## Plans

- Efficient and effective ADS testing and evaluation is an **iterative process** that benefits from collaboration among multiple stakeholders, particularly the ADS developers and IOOs.



Source: FHWA

## Sharing Opportunities

- Data is a key issue that requires thorough discussions with IOO and ADS stakeholders to **avoid challenges**.
- Resource sharing includes sharing of skills and expertise in addition to sharing of information and existing data:
  - ADS Vehicle Data:
    - Raw feed, processed data, actionable items
  - World Data:
    - Roadway, Environment, Objects



Source: FHWA

## Success Factors

- Success comes in **many shapes and sizes**.
- Each phase of testing will have desired and anticipated outcomes.
- The Framework aids in defining test success factors within each test phase.



# Pretest

- Conduct public outreach.
- Identify stakeholders.
- Negotiate data sharing.
- Assess integration challenges.
- Determine testing grounds.
- Obtain proper authorization.

<b>Objective</b>	Conduct activities that help identify a problem. Evaluate collaboration opportunities for successful testing and evaluation.
<b>Inputs</b>	Technology of interest, initial stakeholder contact
<b>Key Activities</b>	<ul style="list-style-type: none"><li>• Programmatic considerations</li><li>• Stakeholder engagement</li><li>• Collaboration opportunities</li></ul>
<b>Outputs</b>	On completion of this phase, you can expect to obtain a clear definition of the goals of collaborative testing. Additionally, you will be able to determine the agreements under which the stakeholders can expect to collaborate.
<b>Plans</b>	<ul style="list-style-type: none"><li>• Stakeholder engagement/agreements</li><li>• Permits, requirements, and insurance</li><li>• Preliminary risk management plans</li><li>• Preliminary public communications</li></ul>

# Test Definition

- Develop test plans.
- Identify key metrics.
- Define evaluation criteria.
- Determine data management requirements.
- Schedule resources.

<b>Objective</b>	Develop a comprehensive test plan, which captures the technical, data, evaluation, and quality facets of collaborative ADS/Roadway testing.
<b>Inputs</b>	Problem definition from the Pretest Phase, stakeholder collaboration assessment
<b>Key Activities</b>	<ul style="list-style-type: none"><li>• Common goals and benefits</li><li>• Problem statement</li><li>• Definition of test success</li></ul>
<b>Outputs</b>	On completion of this phase, you will obtain a comprehensive test plan. You may use the test plan to facilitate test execution. You will also develop a data management plan (DMP), a quality plan, and definition of test success.
<b>Plans</b>	<ul style="list-style-type: none"><li>• Test plan</li><li>• DMP</li><li>• Quality plan</li></ul>

# Test Execution

- Execute test plans.
- Monitor progress.
- Identify gaps.
- Adapt to changes.
- Communicate issues.

<b>Objective</b>	Stakeholders execute testing per the defined test plan. They monitor and adjust program direction to meet defined goals and communication on an ongoing basis.
<b>Inputs</b>	<ul style="list-style-type: none"><li>• Test plan, DMP, quality plans</li><li>• Permits and insurance</li></ul>
<b>Key Activities</b>	<ul style="list-style-type: none"><li>• Operational collaboration</li><li>• Ongoing communications</li><li>• Monitor and adjust program direction</li></ul>
<b>Outputs</b>	<ul style="list-style-type: none"><li>• Collaborative ADS/Roadway testing and evaluation data</li><li>• Deviations in ADS performance and test execution</li></ul>

# Posttest

- Analyze data.
- Document conclusions.
- Evaluate processes.
- Share results.

<b>Objective</b>	Extract insights from testing and evaluation data and share these findings with stakeholders. Conduct project closeout activities that end the collaborative testing and evaluation.
<b>Inputs</b>	<ul style="list-style-type: none"><li>• Collaborative ADS/Roadway testing and evaluation data</li><li>• ADS/Roadway performance and test execution not meeting design intent</li></ul>
<b>Key Activities</b>	<ul style="list-style-type: none"><li>• Data sharing</li><li>• Process improvement and calibration</li><li>• Lessons learned</li></ul>
<b>Outputs</b>	<ul style="list-style-type: none"><li>• Testing and evaluation data insights</li><li>• Lessons learned for future collaborations</li></ul>

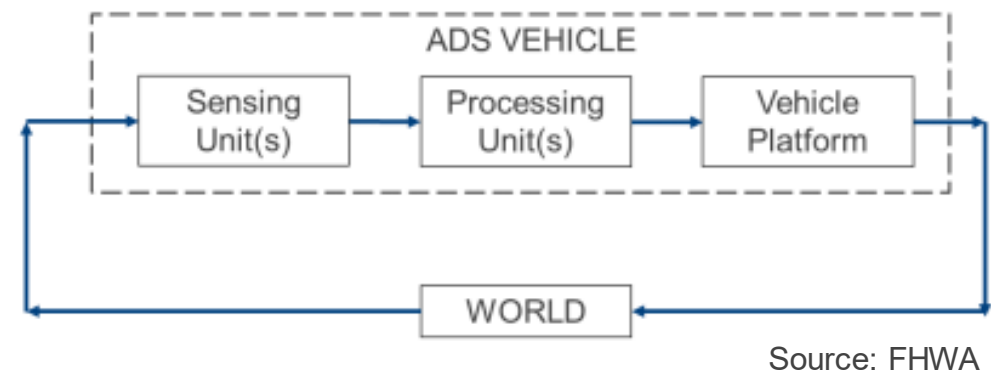
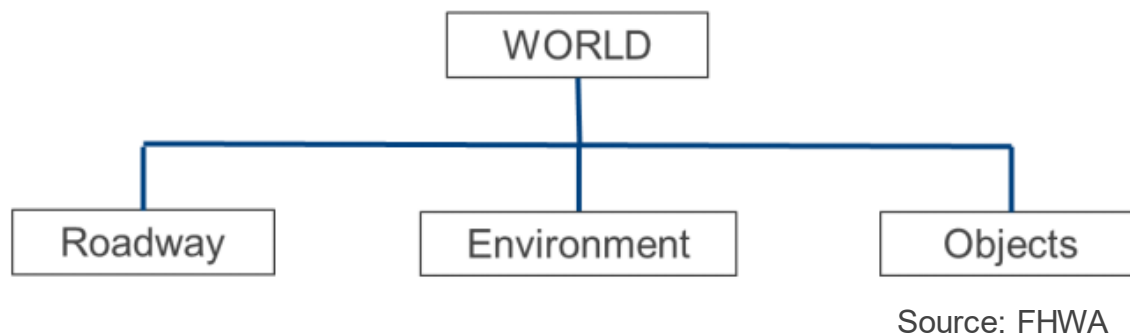
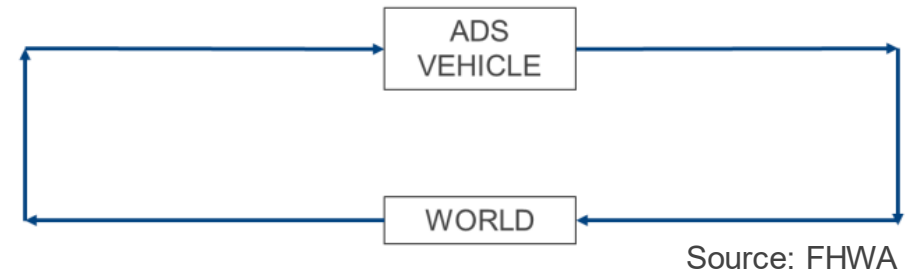
# The Framework Document

- Uses over-arching theme **icons** throughout Framework phases to highlight opportunities when these components may be useful
- Presents **real-world examples** of collaborative ADS and IOO testing
- Identifies **checklists** for various elements
- Utilizes **representative scenario** examples to highlight concepts
- Includes **taxonomy** and **data** appendices
- Accompanied by a **Quick Reference Guide** as a high-level overview of the Framework

Link to the  
***Collaborative Research Framework for ADS Developers and IOOs*** –  
<https://ops.fhwa.dot.gov/publications/fhwahop21012/fhwahop21012.pdf>

# ADS/Roadway Perception Functionality

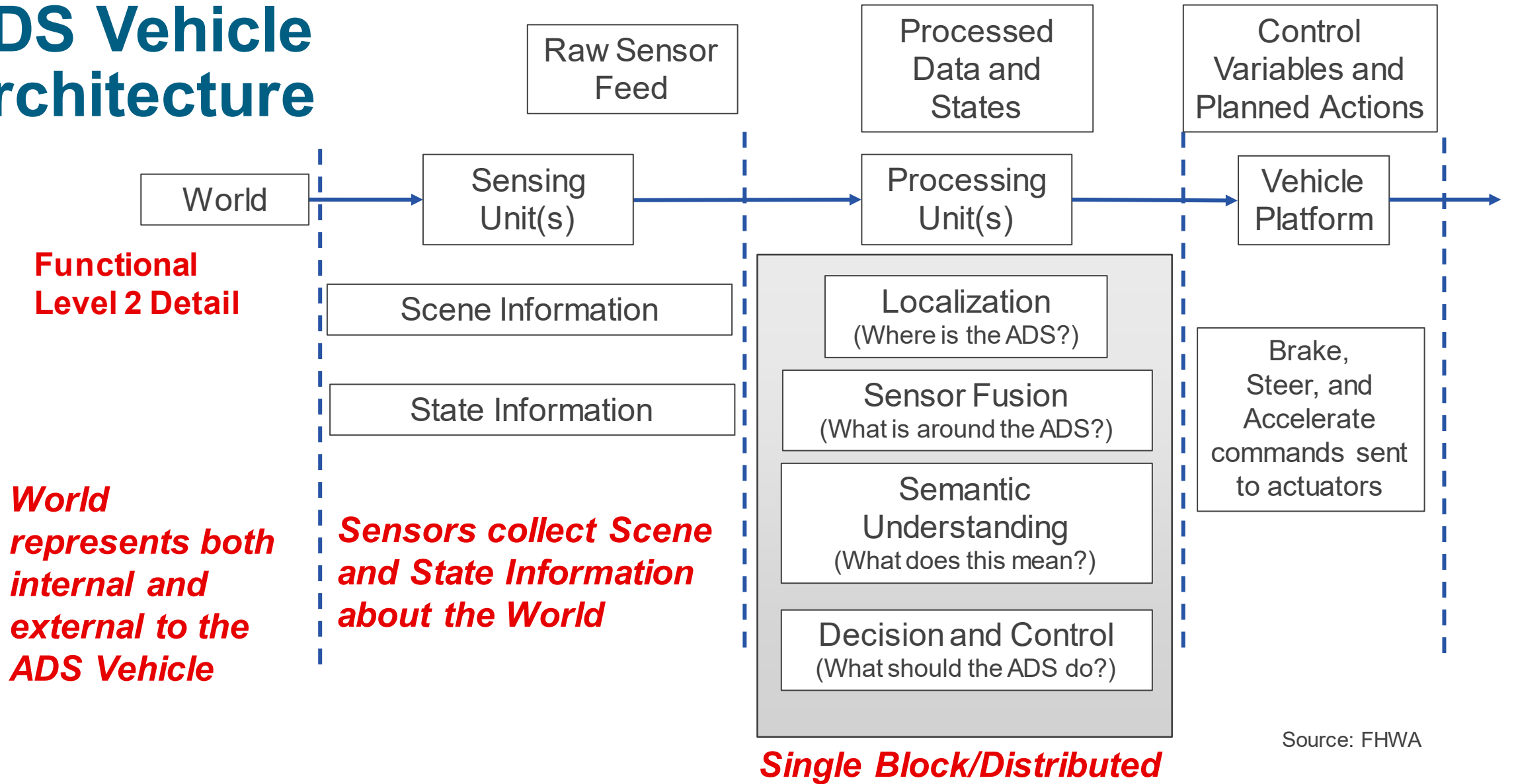
- **Purpose:** To develop a functional understanding of ADS and infrastructure testing and evaluation and clearly describe it
- Adds to framework development, to include:
  - Understanding of a joint ADS Vehicle/World system
  - A **language and taxonomy** for the ADS Vehicle and World modules and their parameters



# Taxonomy Breakdown

- ADS Vehicle Architecture:
  - Sensing
  - Processing
  - Vehicle Platform
- World
- Work Zone Example:
  - Description
  - Goals

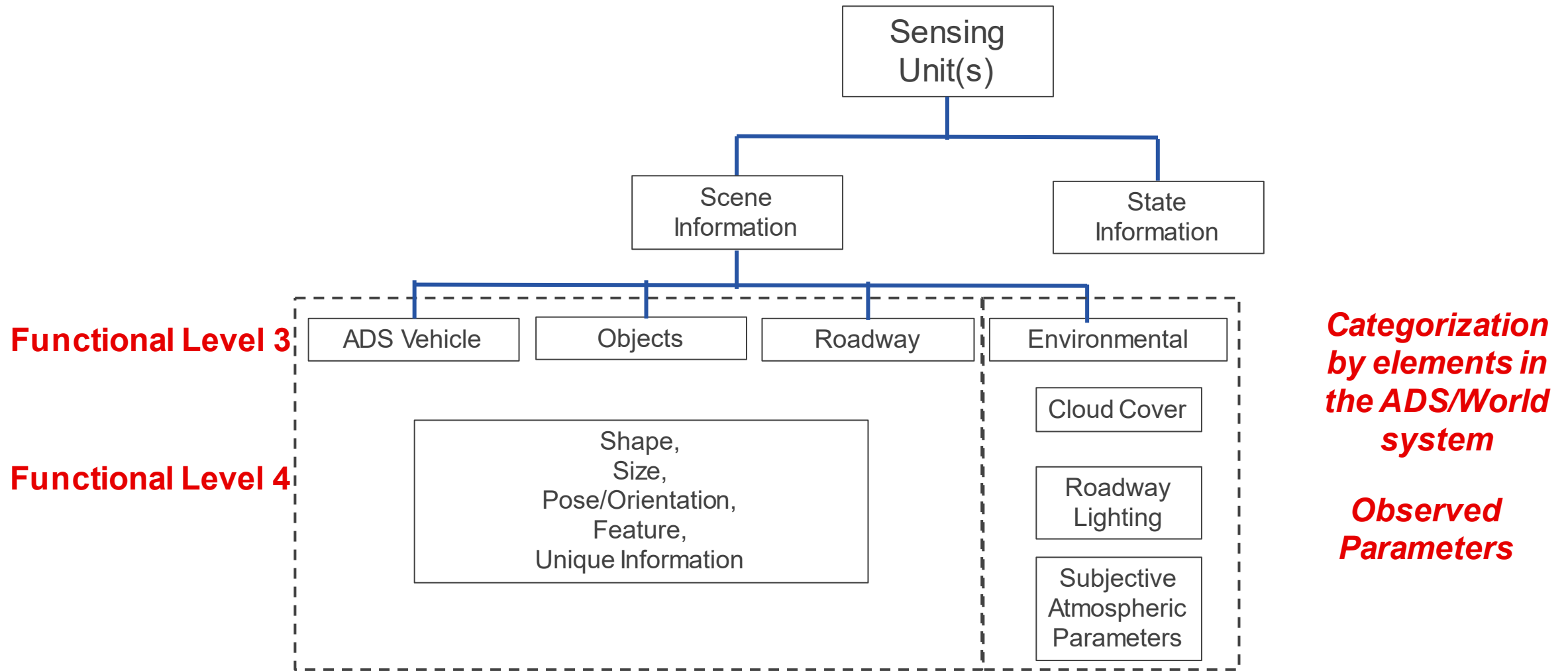
# ADS Vehicle Architecture



Source: FHWA

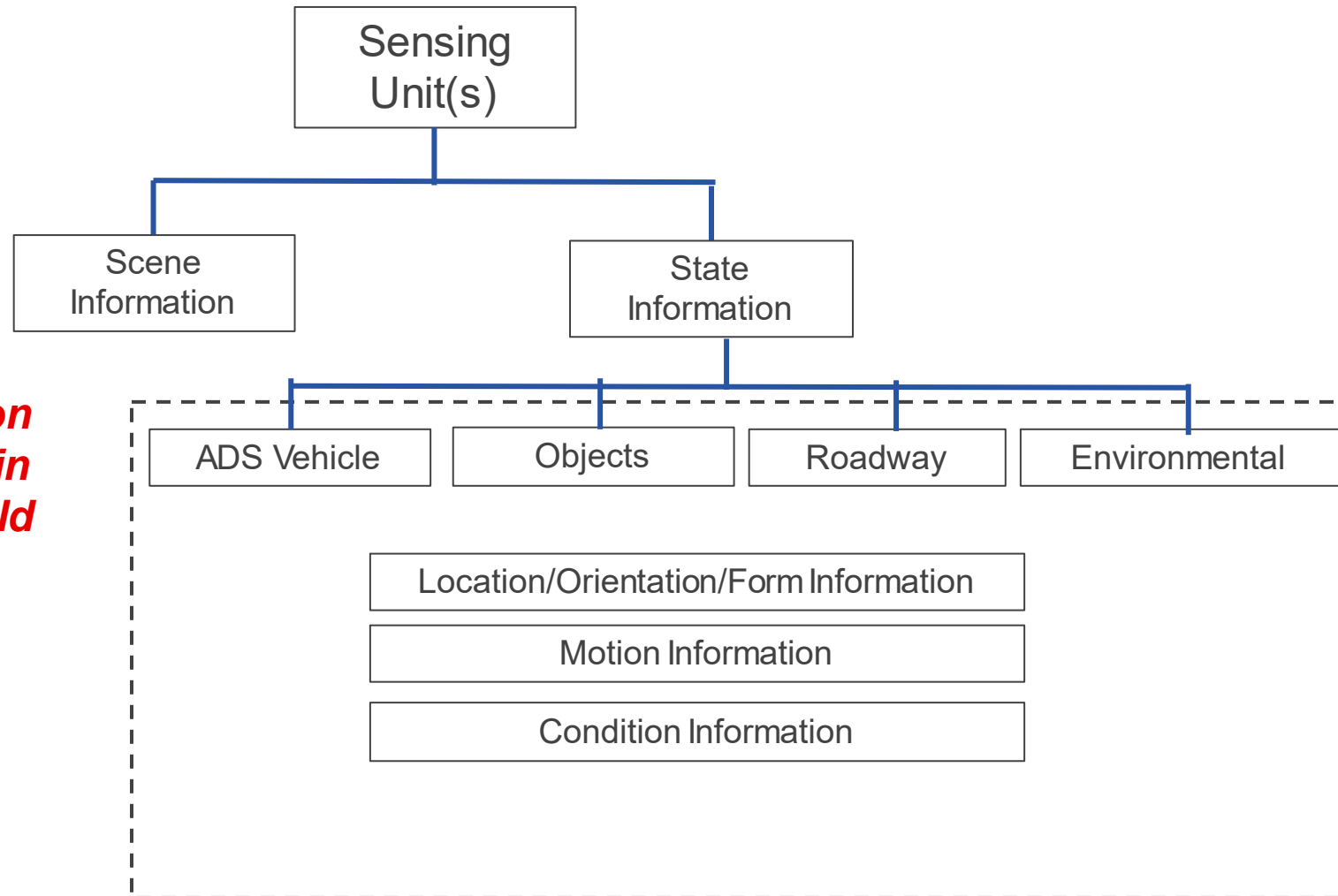


# ADS Sensing Unit – L3 and L4 Scene Info



Source: FHWA

# ADS Sensing Unit – L3 and L4 State Information



**Categorization  
by elements in  
the ADS/World  
system**

**Functional Level 3**

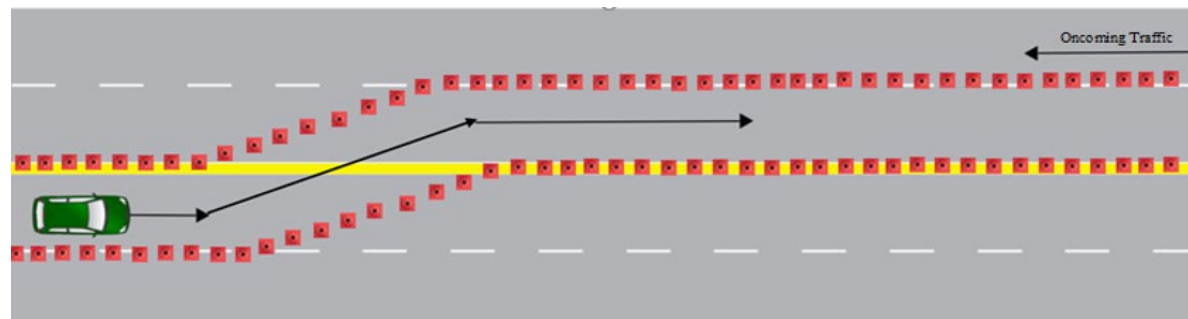
**Functional Level 4**

**Observed  
Parameters**

Source: FHWA

# Work Zone Navigation

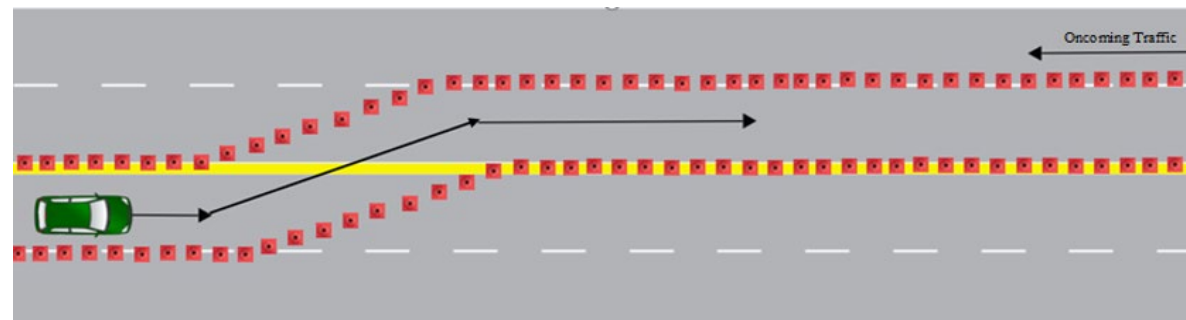
- ADS with lane centering with adaptive cruise control (SAE L3) that:
  - Detects a work zone ahead
  - Safely follows construction barrels/cones in work zones
- Test goals:
  - Understand how an ADS vehicle reacts when approaching a work zone
  - Understand how cone placement affects ADS performance
  - Understand how lighting affects ADS performance



Source: FHWA

# Work Zone Navigation – Program Definition Phase

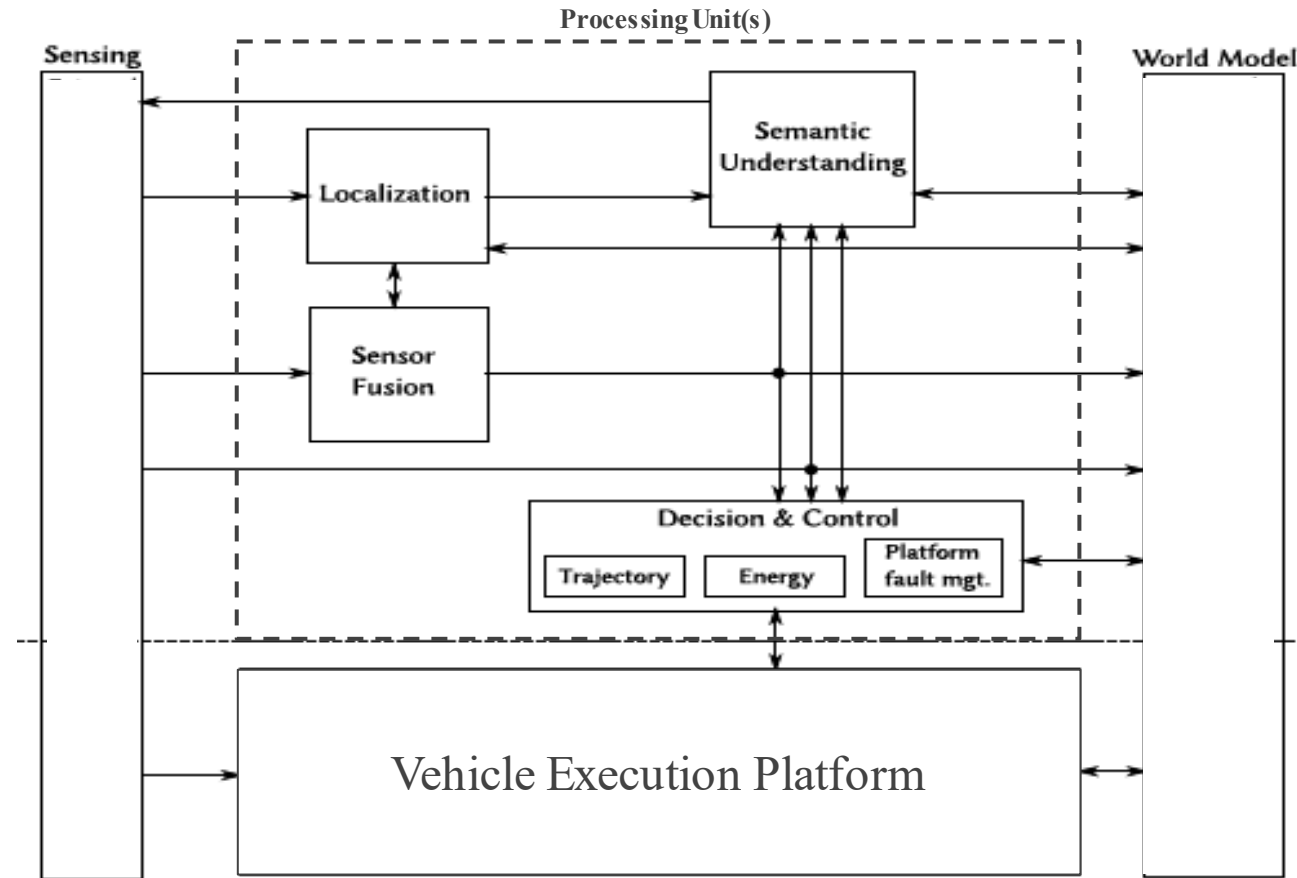
- Test scenario: Joint ADS/World System
  - ADS-equipped subject vehicle:
    - ADS user (test speed of 45 mph) activates the L3 system before entering a construction zone with a lane shift.
    - ADS user does not provide manual inputs to accelerator, brake, or touch steering wheel.
    - ADS detects other road users in path but may be confused when objects are in redirected route.



Source: FHWA

# ADS Processing Unit(s) – High Level

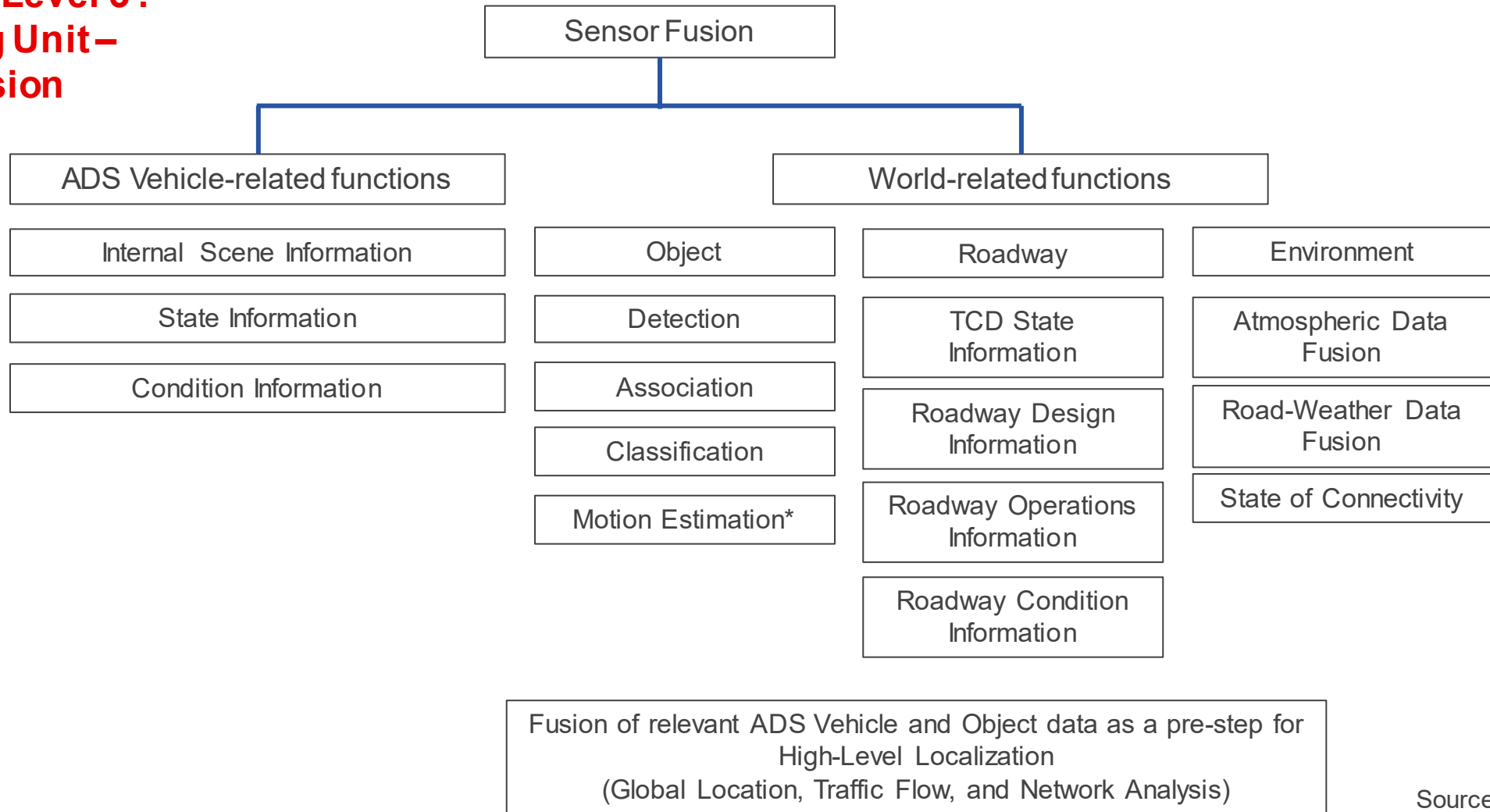
## Functional Level 2



Source: Behere, S. and M. Torngren. 2015. "A Functional Architecture for Autonomous Driving." In *2015 First International Workshop on Automotive Software Architecture (WASA)*, pp. 3-10.

# ADS Processing Unit(s) – Sensor Fusion

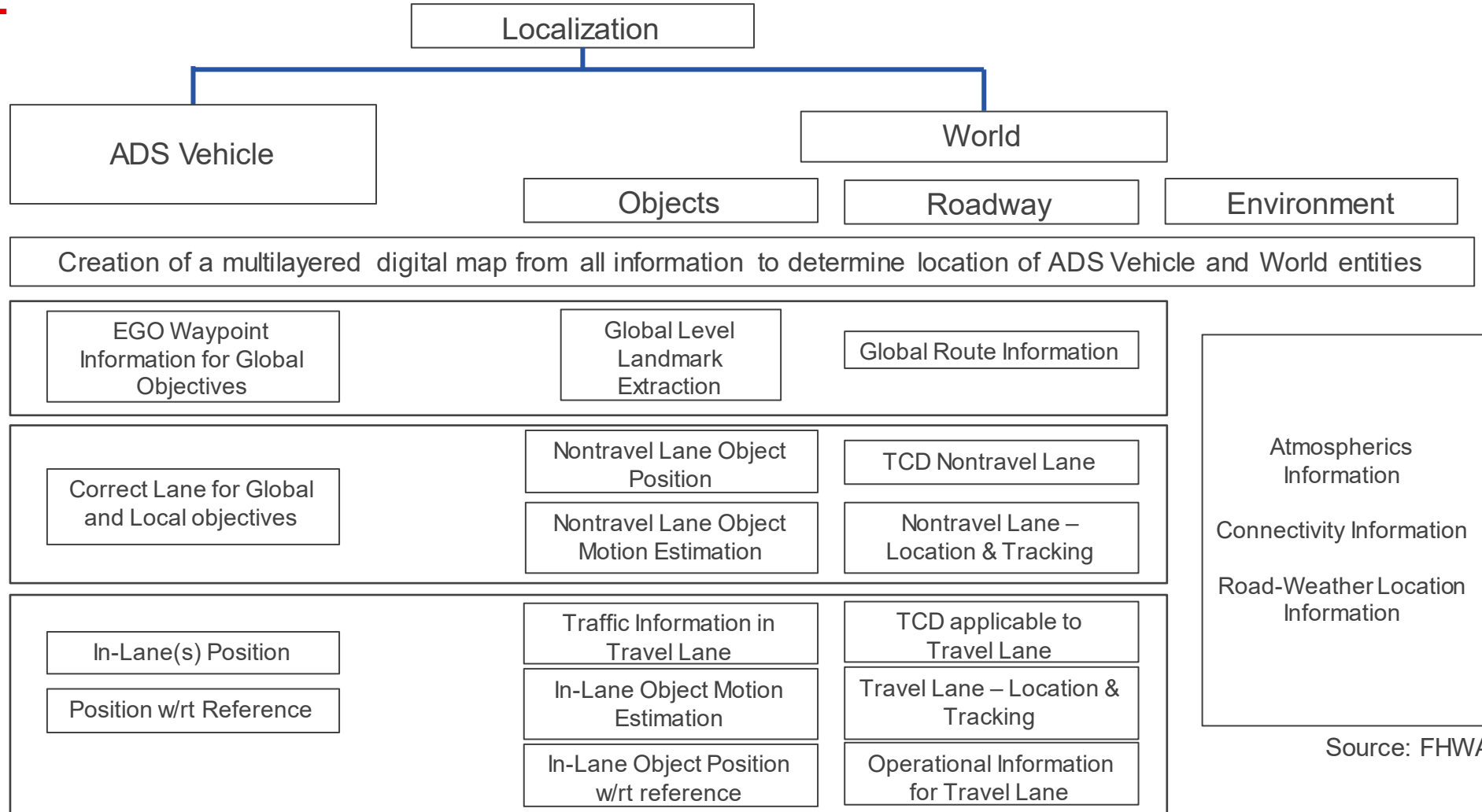
## Functional Level 3: Processing Unit – Sensor Fusion



Source: FHWA

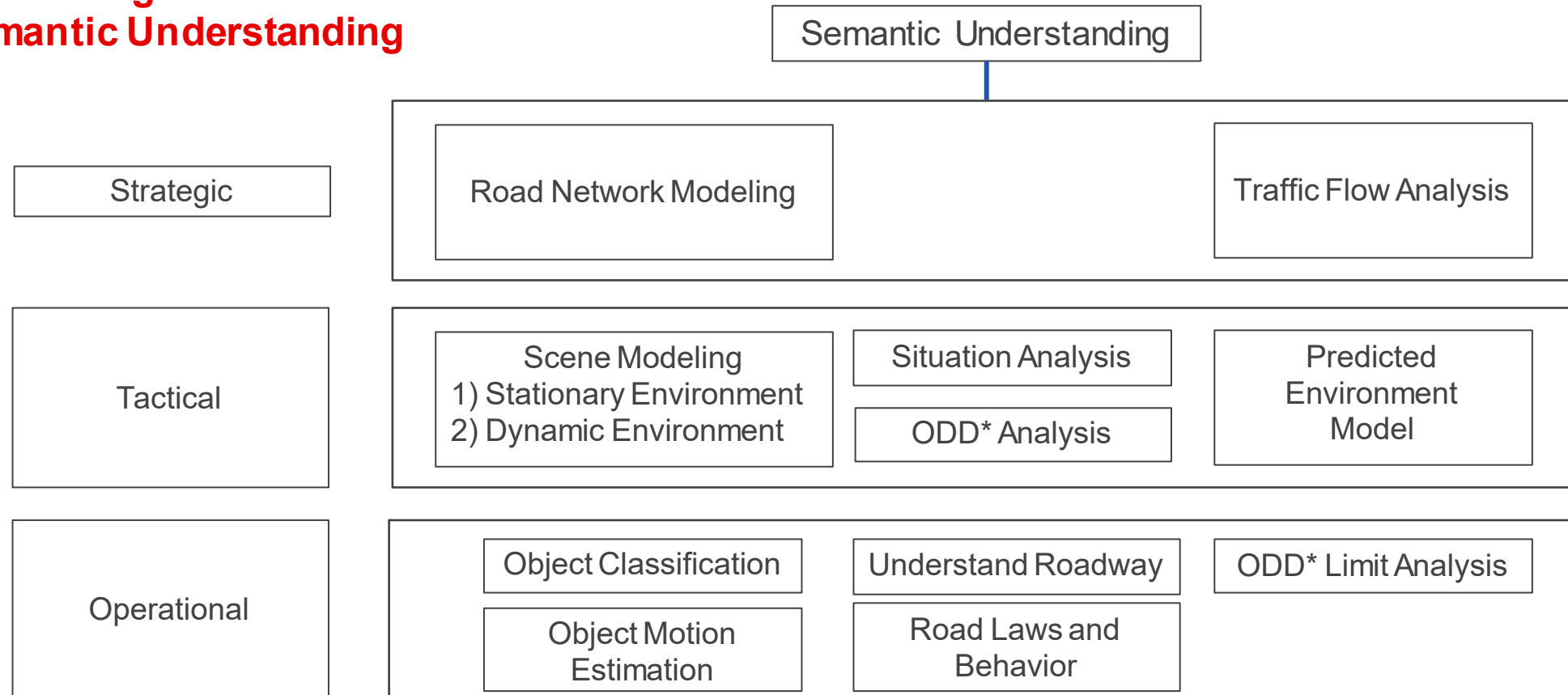
# ADS Processing Unit(s) – Localization

## Functional Level 3 : Processing Unit– Localization



# ADS Processing Unit(s) – Semantics

## Functional Level 3 : Processing Unit– Semantic Understanding



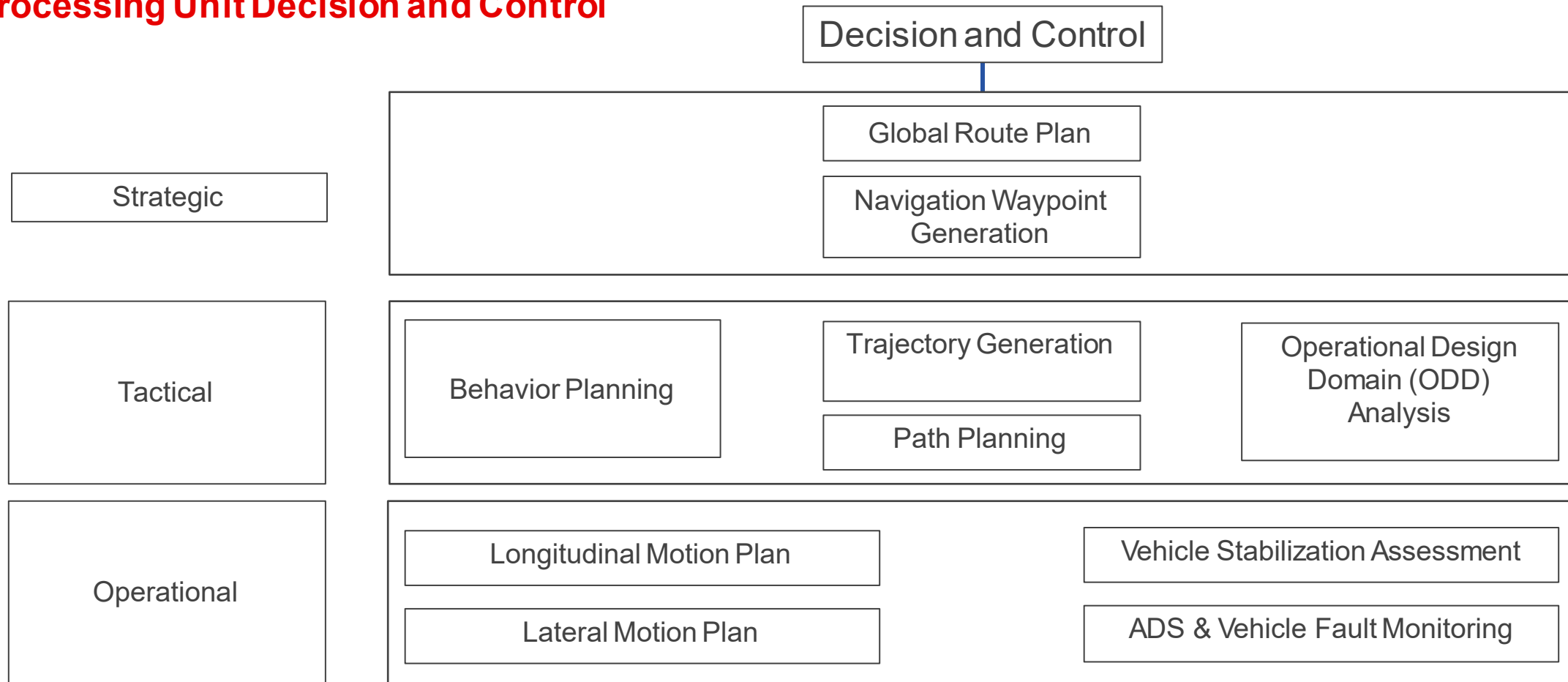
\* Operational Design Domain (ODD)

Source: FHWA



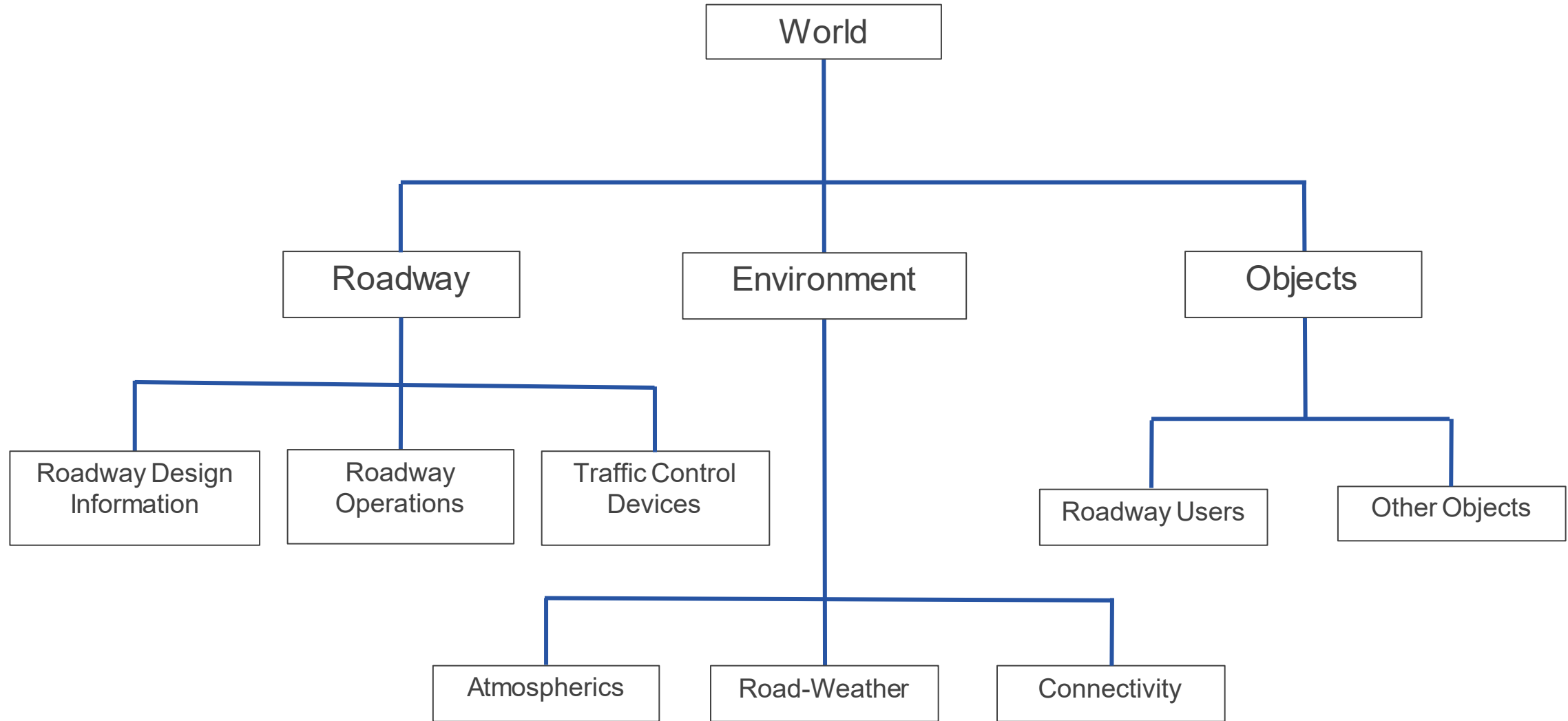
# ADS Processing Unit(s) – Decision and Control

## Functional Level 3 – Processing Unit Decision and Control



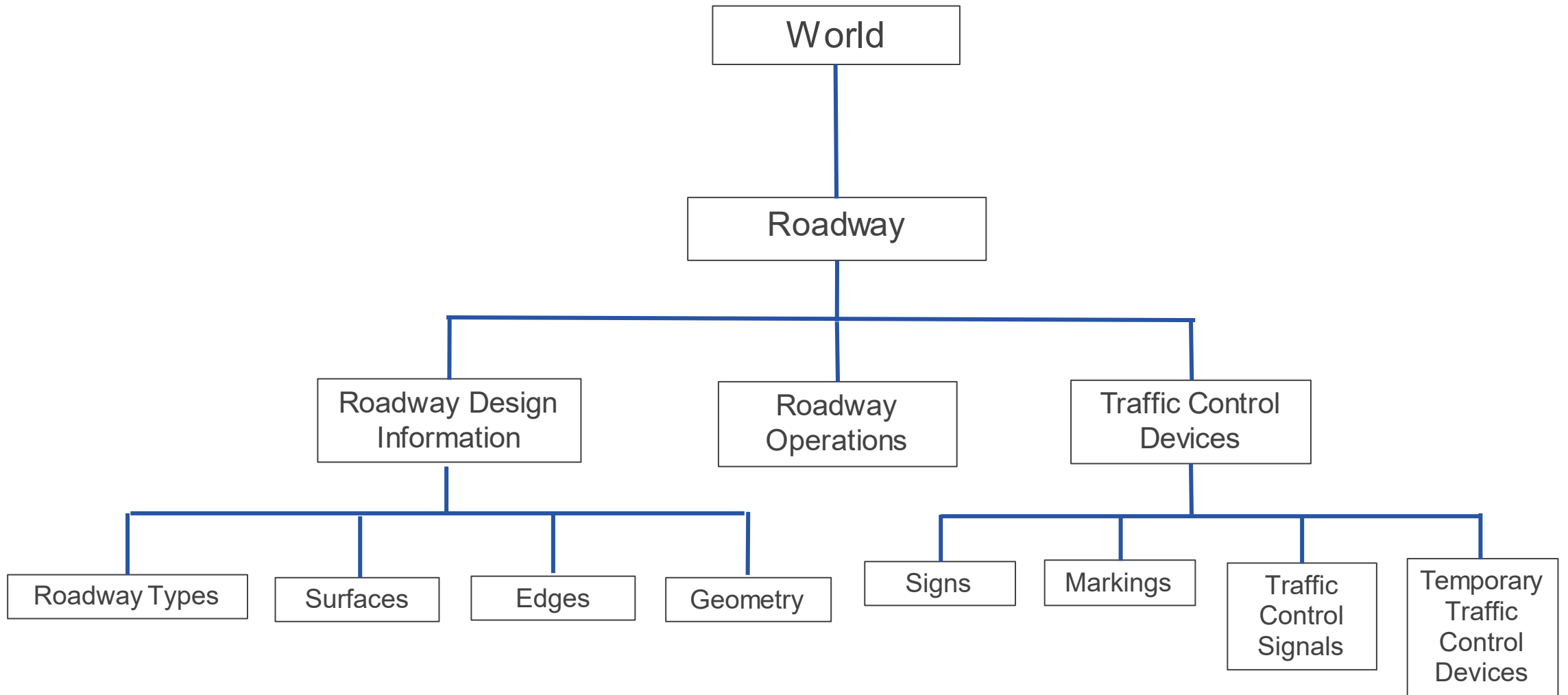
Source: FHWA

# World Classification



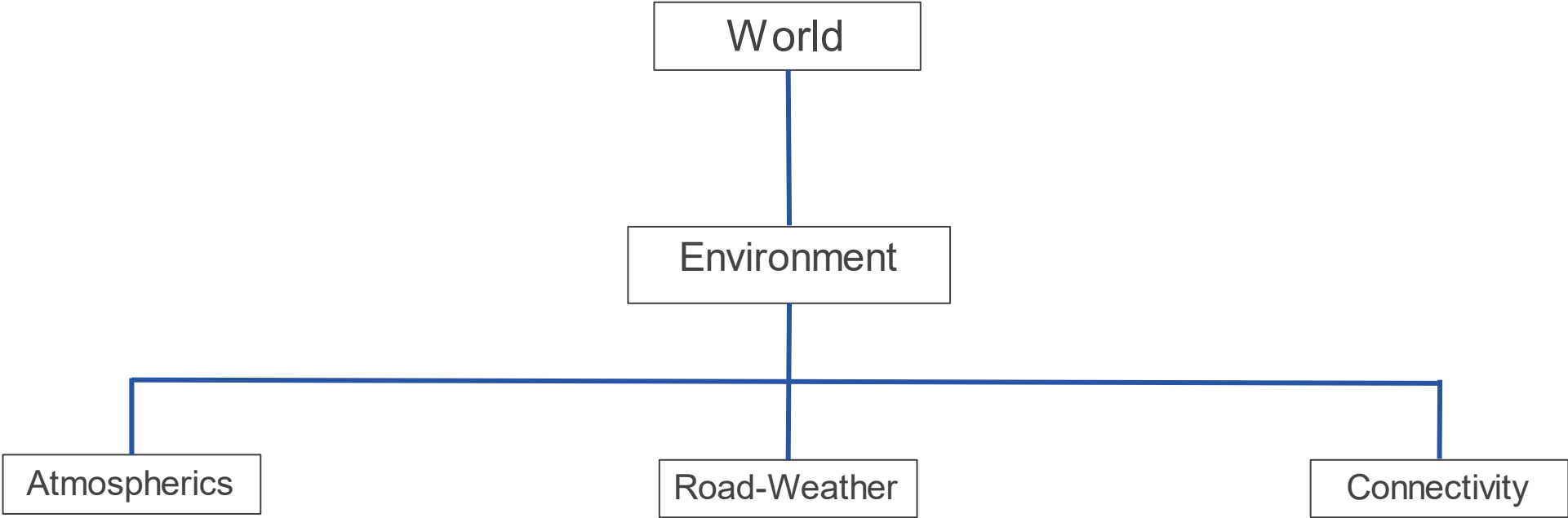
Source: FHWA

# Roadway Classification



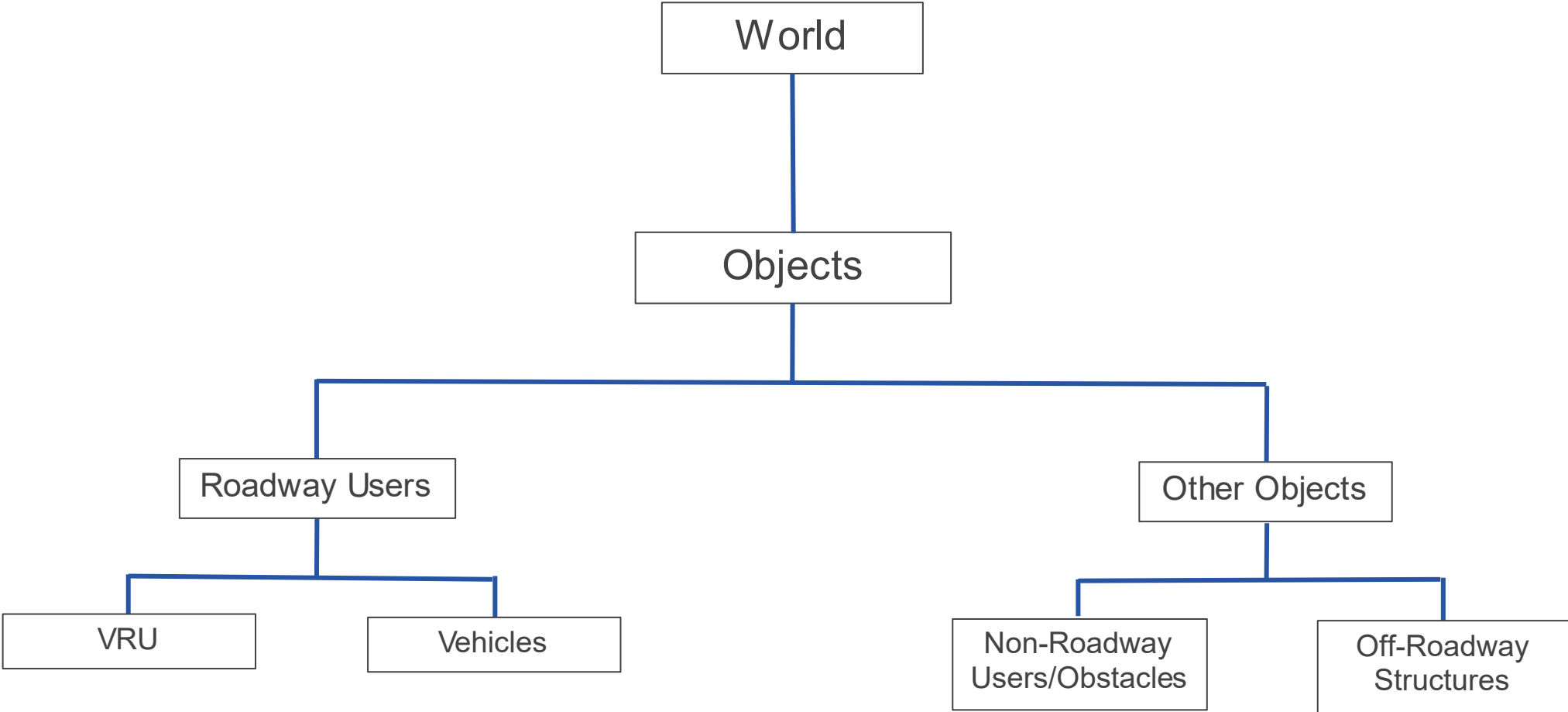
Source: FHWA

# Environment Classification



Source: FHWA

# Object and User Classification



Source: FHWA

# Work Zone Navigation Feature – Program Definition Phase

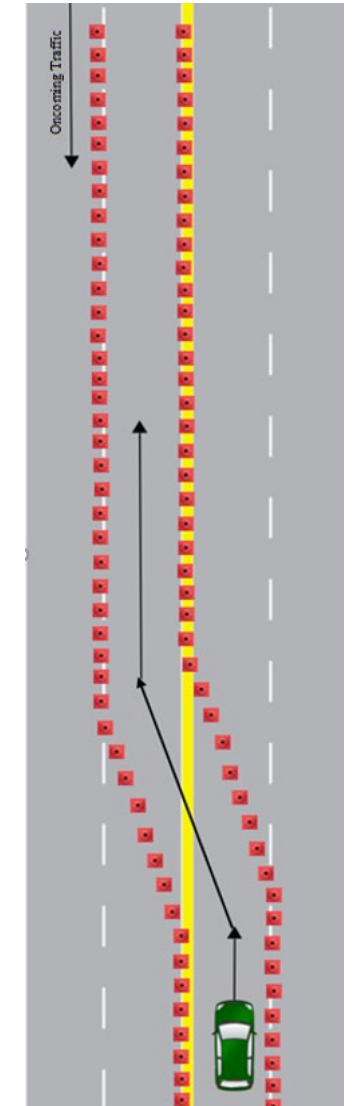
## World Description:

### World: Environment: Atmospheric

Essential Climate Variables	Ambient Temperature	32°F – 104°F
	Wind Speed	Less than 22 mph
	Precipitation	No inclement weather
Visibility	Distance	3 miles
	Time of Day	Full sun in line with vehicle

### World: Roadway: Roadway

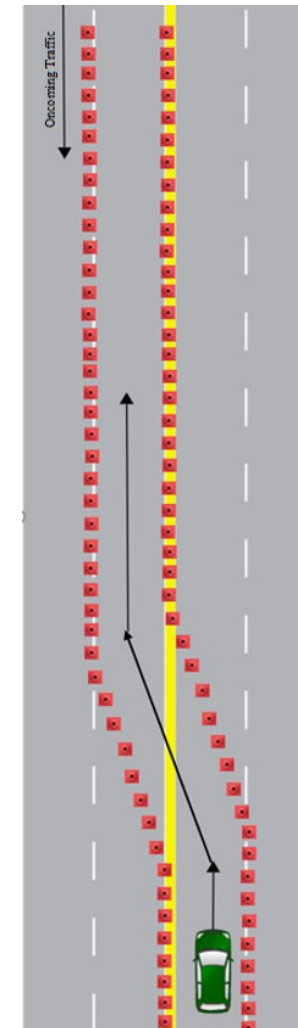
Type of Roadway	Highway
Number of Travel Lanes	Three
Roadway Width	N/A
Lane Width	10–12 ft
Shoulder Presence	Yes, but coned off/not accessible
Surface Type	Concrete
Radius of Curvature	Straight Lanes
Grade	Between Level and 1%



Source: FHWA

# Work Zone Navigation Feature – Program Definition Phase

World: Roadway: Roadway – Traffic Control Devices	
Signing	Work Zone Ahead Sign Reduced Speed Limit (45 mph)
Lane Marking Type Right to Left	<b>Solid White and Barrels</b> Initial Travel Lane (Ends) <b>Double Solid Yellow and Barrels</b> New Travel Lane <b>Dashed White and Barrels</b> Oncoming Travel Lane <b>Solid White</b>
Lane Marking Condition	Retro-reflectivity of lane markings are degraded, other aspects meet or exceed recommendation
Lane Marking Color	Yellow and White mentioned as above (Acceptable per National Institute of Science and Technology Reference)
Lane Marker Width	4–6 in



Source: FHWA

# For Additional Information

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202-366-5665

*Collaborative Research Framework for Automated Driving System Developers  
and Infrastructure Owners and Operators*

**Publication Number: FHWA-HOP-21-012**

<https://ops.fhwa.dot.gov/publications/fhwahop21012/fhwahop21012.pdf>