Infrastructure Recommendations for Automated Vehicles (AVs)

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NCHRP NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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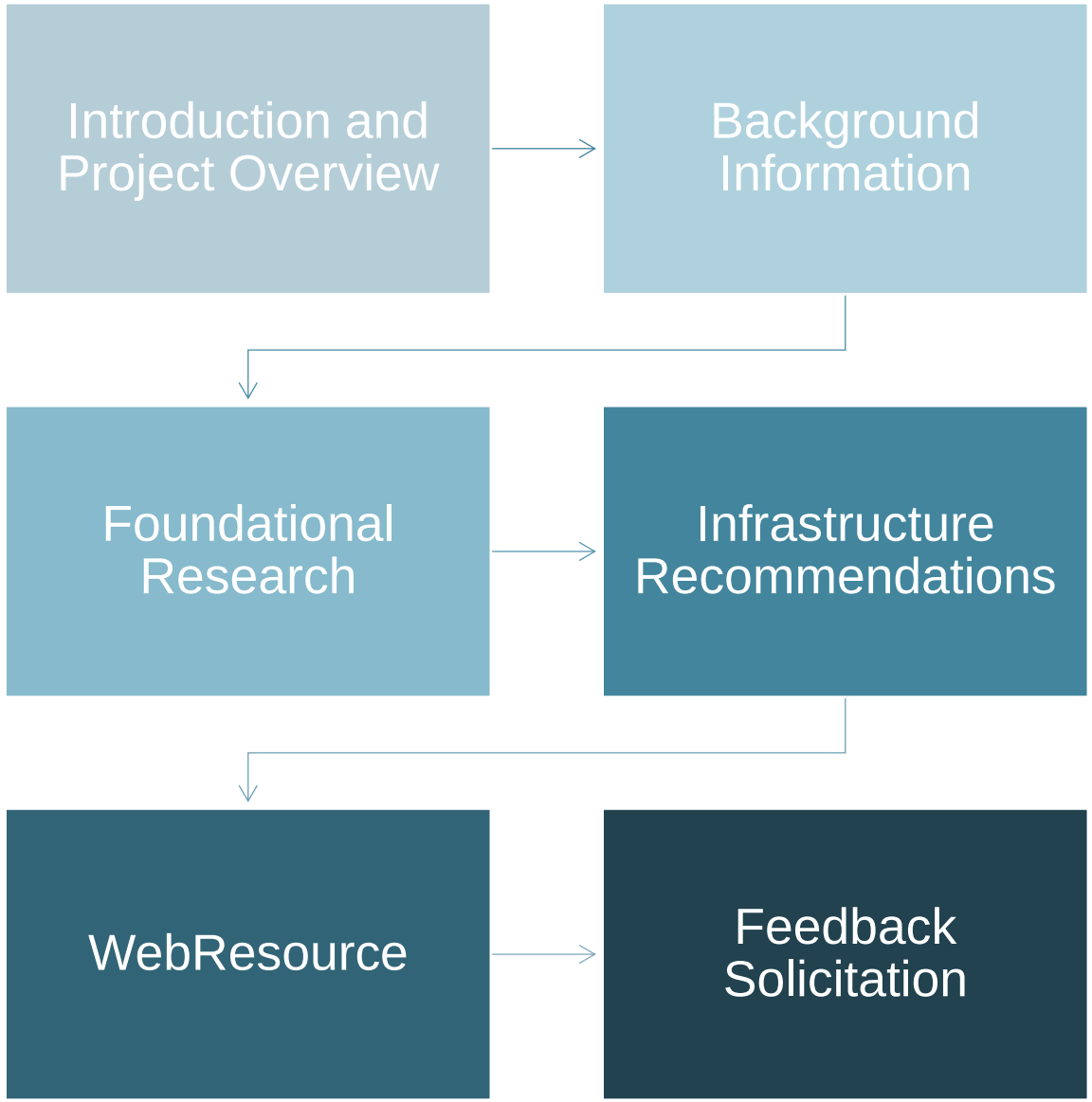
Agenda


Introduction and Project Overview
Background Information
Foundational Research
Infrastructure Recommendations
WebResource
Feedback Solicitation

Project Overview

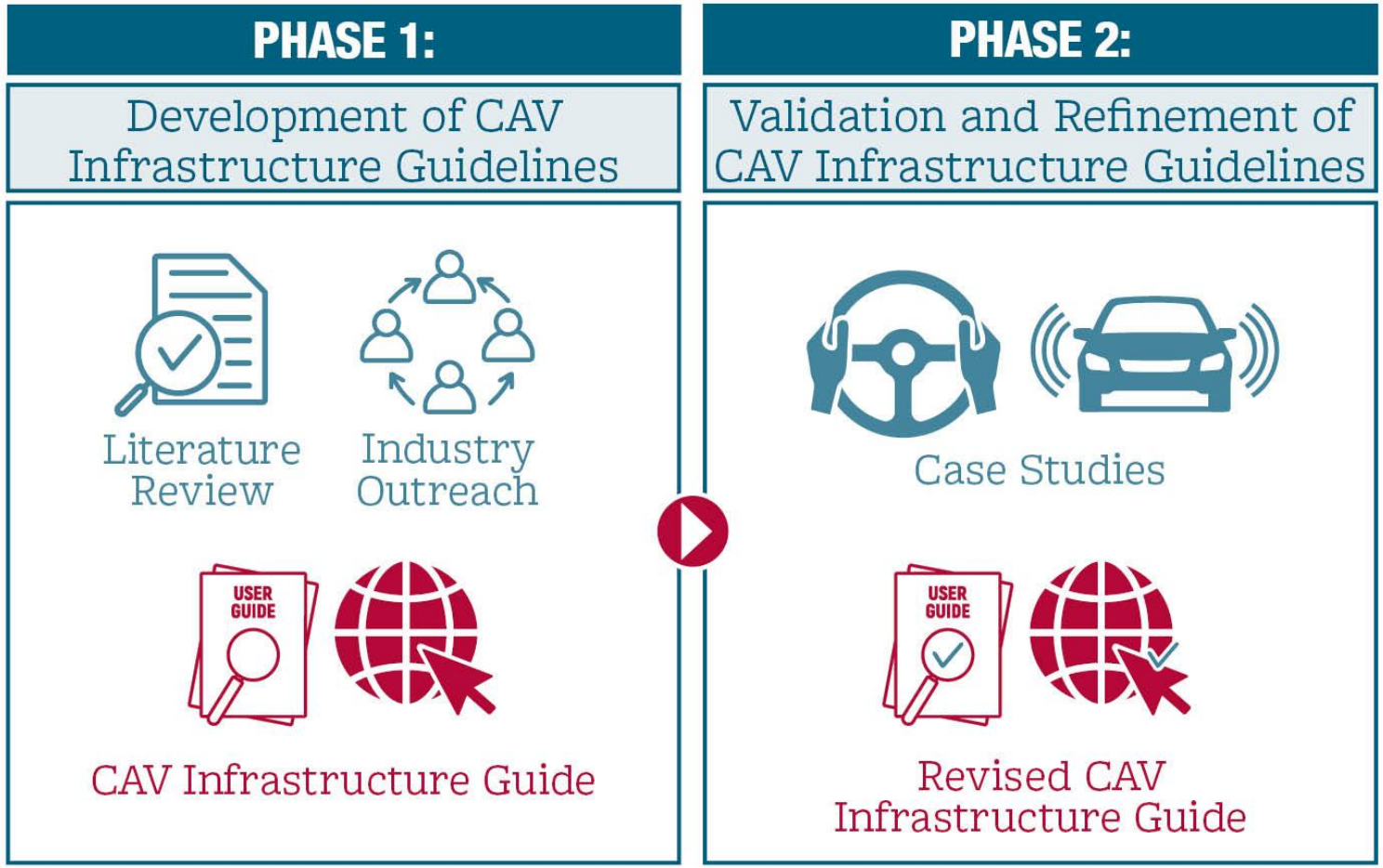
NCHRP 20-102(24) Objectives

- Enhance IOO **understanding** of infrastructure impacts on AV technology deployment.
- Support IOOs in **prioritizing** infrastructure treatments with the greatest impact on safe and efficient AV adoption.
- Document with **clear, concise, & easy-to-use guidelines** that can be readily personalized and implemented by agencies.

NCHRP 20-102(24) Research Approach

- Answer research question: How does physical infrastructure influence the **operational domain** of **driving automation systems**?
- Collaboratively develop **physical infrastructure guidance** to support a smooth transition to AV deployment
  - Focus on physical infrastructure, touch on digital infrastructure
- Verify the validity and effectiveness of the guidelines by conducting **case studies** exploring the proposed infrastructure improvements

NCHRP 20-102(24) Research Approach



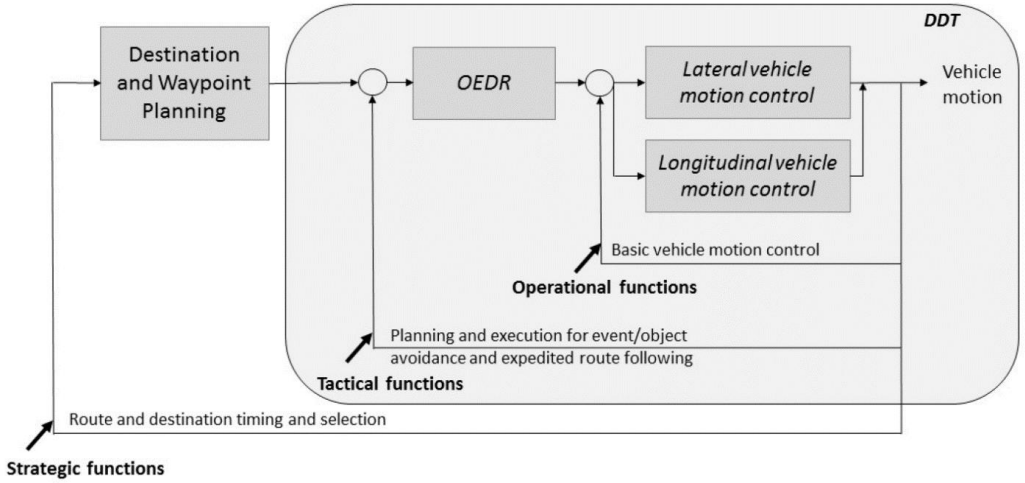
- 3-Year Project, concluding in November 2026
- Phase 1 complete, Phase 2 underway
- Actively collecting feedback on draft Guide

Background Information

Dynamic Driving Task (DDT)

- **Real-time operational** and **tactical functions** required to operate a vehicle in on-road traffic:
  - Steering
  - Acceleration/deceleration
  - Object/event detection, recognition, classification, and response
  - Maneuver planning

Schematic of Driving Task Highlighting the DDT Portion

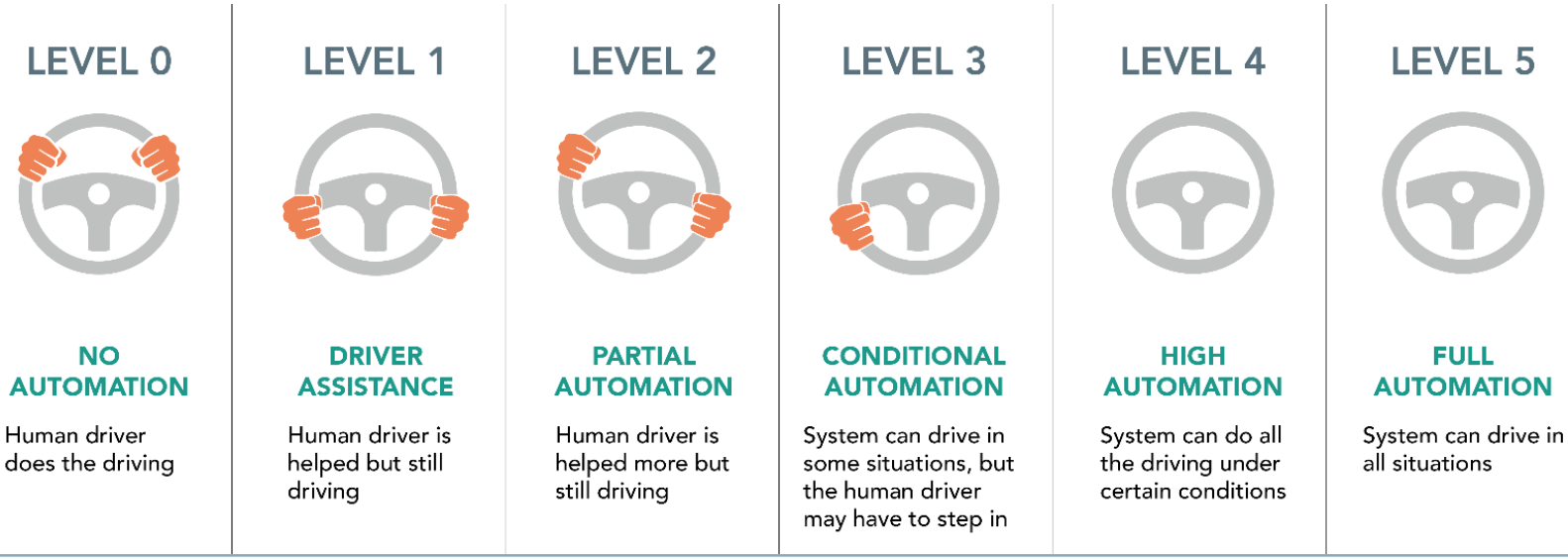


Source: SAE International J3016, 2021

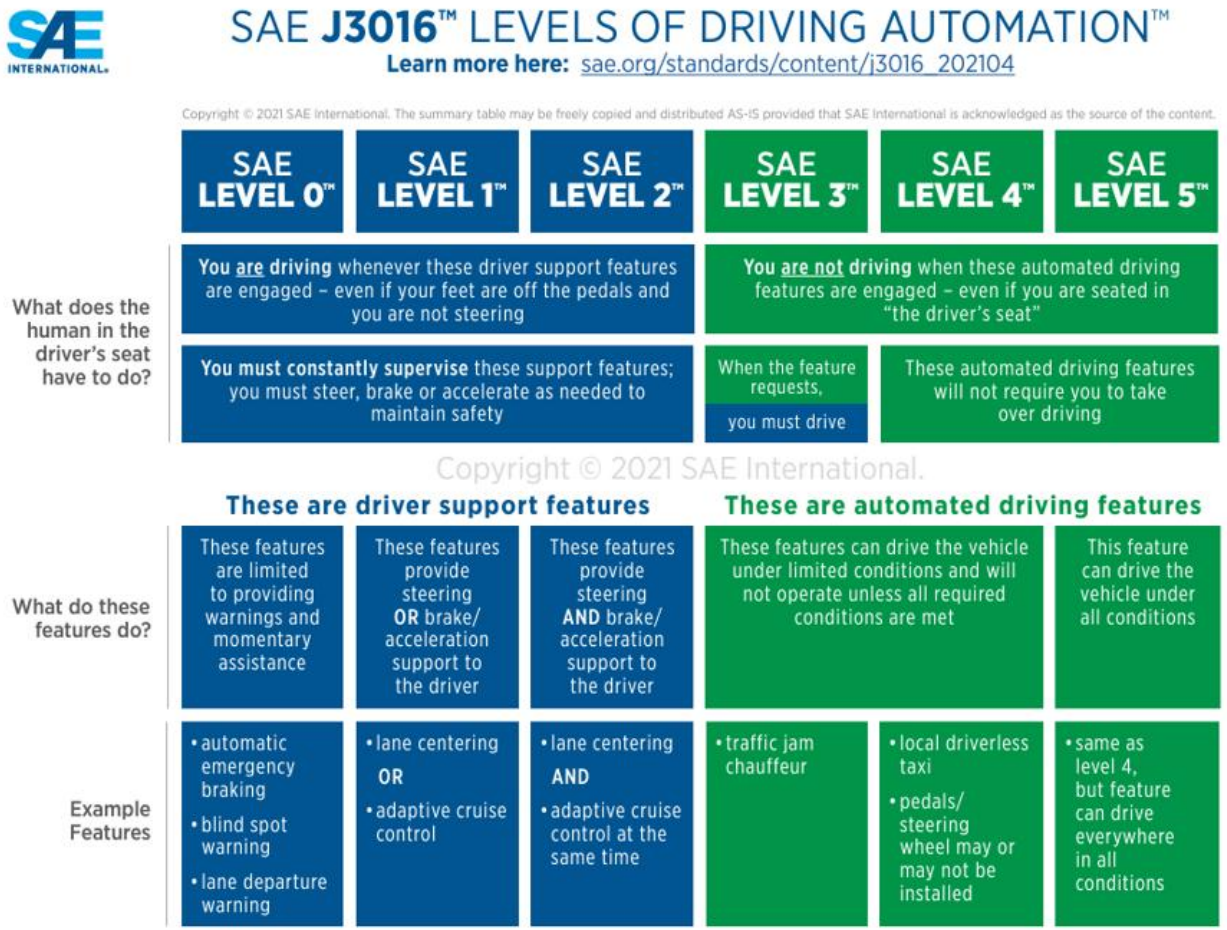
Reference: SAE J3016

Driving Automation Systems

- **DAS**: Formal term for automating an element of the Driving Task
- SAE defines level of driving automation based on the **functionality of the DAS**
- This determines the **division of responsibility** between the automated system and the human operator performing specific aspects of the dynamic driving task



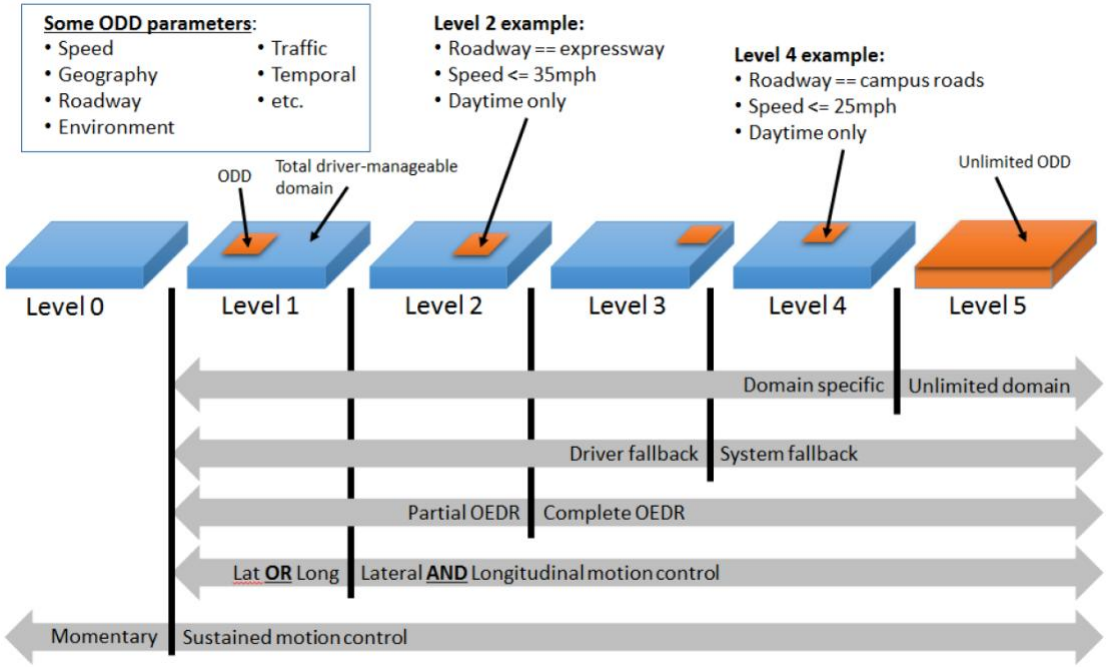
- **Advanced Driver Assistance Systems (ADAS)**
  - Level 1 or 2 (operator full attention)
  - Features that provide warnings and/or momentary interventions (FCW, LKA, AEB, ACC)
- **Automated Driving System (ADS)**
  - Level 3, 4, or 5 (reducing operator attn)
  - Features that take over portions of the driving task (traffic jam assist, driverless taxis/buses)



Source: SAE International J3016, 2021

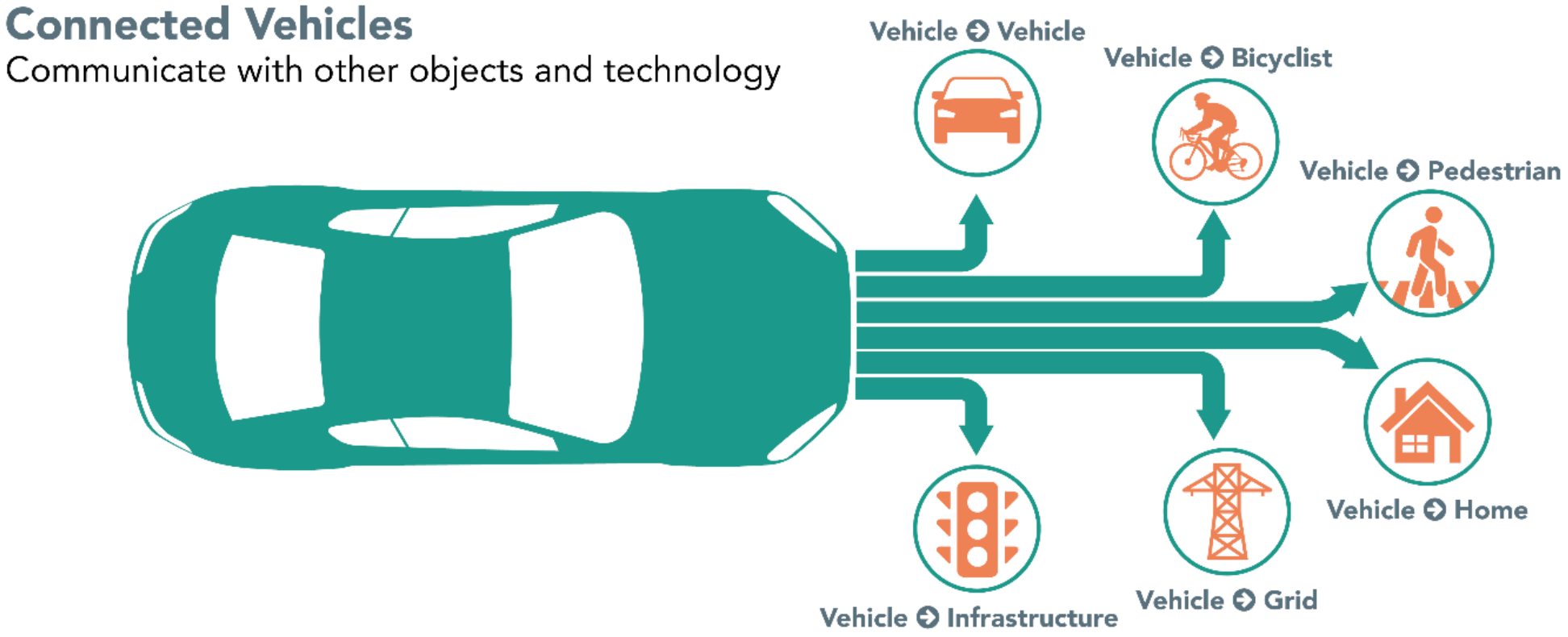
Operational Design Domain (ODD)

- Operating conditions under which a given feature is **designed to function**
  - Specific road types
  - Travel speed
  - Weather conditions
  - Road features
  - Maintenance conditions of road Geographical restrictions (campuses/routes)
  - Lighting conditions



Source: SAE International J3016, 2021

Vehicle Connectivity



Foundational Research Literature

Physical Infrastructure Literature

- Physical infrastructure can **limit the ODD** due to **inconsistencies** in design, placement, and maintenance of traffic control devices
- **Dynamic and unique scenarios** (such as work zones) present additional challenges to driving automation systems

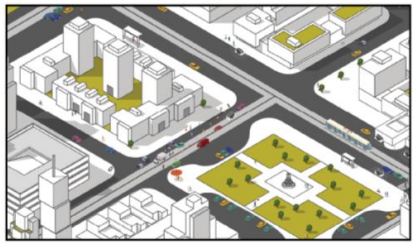
Types of Physical Infrastructure Reviewed:


Pavement Markings


Roadway Surface


Traffic Signs


Traffic Signals


Temporary Traffic Control Work Zones


Geometric Design

Digital Infrastructure Literature

- Digital infrastructure is considered an **enabling technology** that may help overcome challenges associated with physical infrastructure and complex driving environments
- **ITS deployments** have been considered a metric by which to measure the readiness for deploying CV-enabled infrastructure

Types of Digital Infrastructure Reviewed:

- Cybersecurity
- Work Zone Information
- Asset Management Data
- Real-Time Data
- Tunnel Signal Repeaters
- Emergency Vehicle Presence and Routing
- HD Maps
- ITS / Roadside Equipment

Limitations in Published Literature

- For-profit AV Industry – **disincentivizes publishing deficiencies**
- Limited reports on disengagements and control algorithm errors in **complex environments**
- Published literature represents studies often performed in an academic setting with **non-production-grade** algorithms and equipment
- **Evaluation/certification protocols** for the safety of AVs are still being developed

Foundational Research
AV Industry Feedback

Common Themes from AV Industry

- **Consistency Across Infrastructure:** Uniformity is crucial
- **HD Maps:** Maintaining high-quality HD maps helps to address numerous infrastructure challenges
- **Unpredictable Road Users:** The greatest challenge for AVs is the unpredictability of other road users, especially in ambiguous situations caused by inferior infrastructure
- **Mutual Benefits:** Infrastructure improvements for AVs also enhance safety and usability for human drivers
- **Public Education:** Accelerating public education on AVs is needed to spur safe adoption

AV Industry Recommended Investments

Physical Infrastructure

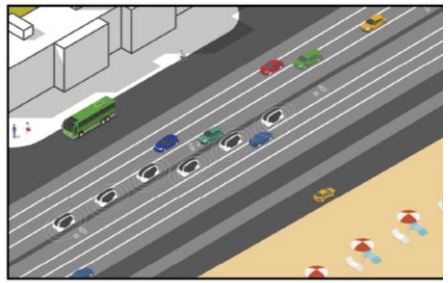
- Pavement Markings:
  - Enhanced visibility, consistent application (contrast, size, patterns, colors)
- Non-Motorized Road User Safety:
  - Separation and channelization in urban areas
- Improved Sight Distance:
  - Enhanced visibility for permissive and complex intersections
- Safe Harbor Locations:
  - Designated shouldering areas on highways

Digital Infrastructure

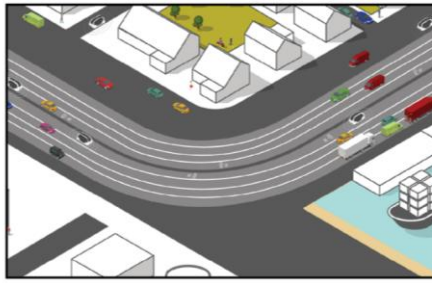
- Real-Time Information:
  - Work zones, special events, crashes – centralized APIs (e.g., WZDx) and C-V2X
- Emergency Vehicle Data:
  - Presence and routing information broadcasting
- Signal Timing Information:
  - Increased accessibility to signal timing and phasing data

Infrastructure Recommendations

Categories of Recommendations



Pavement Markings

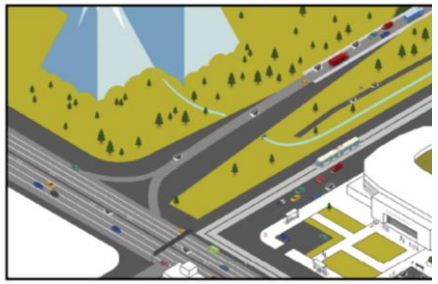


Roadway Surface

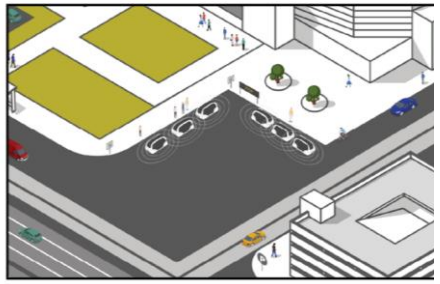
Traffic Signs

Traffic Signals

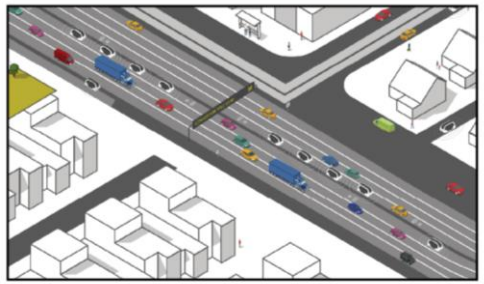
Temporary Traffic Control /Work Zones



Geometric Design



Digital Infrastructure



Policy and Procedures

Example of Disengagement

Case Studies Conducted by the University of Cincinnati

Infrastructure Recommendations

Pavement Markings

Visibility / Width

- Retrorelectivity
  - Literature indicates a minimum retroreflectivity of 150 $mcd/m^2/lx$ under dry conditions
- Contrast
  - Contrast ratio of 3:1 is the minimum threshold for machine vision detection
- Width
  - Standardize the width of pavement markings to 6 inches

Raised Pavement Markers

Use raised pavement markers to **supplement not replace** painted markings

Missing Pavement Markings

Access-Controlled Facilities

- Provide dotted line extensions along all entrance and exit ramps and auxiliary lanes

Gore Areas

- Provide chevron markings in gore areas to differentiate the exit lane from the travel lane

Missing Pavement Markings

Intersection Turning Guidelines

- Implement dotted line markings for both centerlines and edge lines to enhance wayfinding at intersections.

Infrastructure Recommendations

Roadway Surface

Pavement Maintenance

Crack Sealing and Joints

- Use sealing materials that blend with the pavement

Potholes

- Establish a comprehensive management program

Ghost Markings

- Employ effective removal techniques and proper resurfacing

Infrastructure Recommendations

Traffic Signals

Size, Brightness, and Visibility

- Standardize traffic signal heads to 12-inch diameters with high brightness LEDs
- Limit overcrowding of signal heads with signs or downstream signals and by adding black or yellow backplates

Infrastructure Recommendations

Other Categories

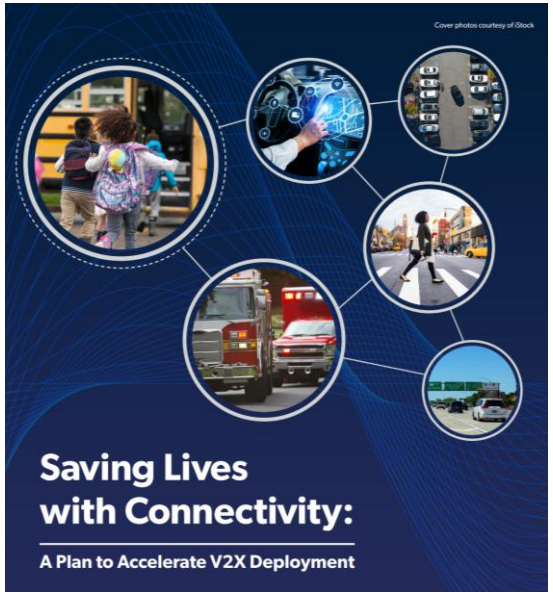
Traffic Signs

- Standardization/Uniformity
- Chromaticity & Retroreflectivity
- Overcrowding/Occlusion
- Placement
- Electronic Signage
- School Zone Signage
- Bike Lane Signage
- Scannable Technology

Temporary Traffic Control / Work Zones

- Standardization in Signage, Markings, and Traffic Control Devices
- Incomplete Removal of Previous Markings
- Traffic Flow Channelization
- Traffic Control Device Visibility
- Presence of Roadside Workers

USDOT's Goal for V2X Deployment



***Source**: U.S. Department of Transportation, 2024*

Medium-Term

- V2X deployed on **50% of National Highway System**
- Top 75 metro areas have **50% of signalized intersections** V2X enabled

2025 2027 2029 2031 2033 2035

2024 2026 2028 2030 2032 2034 2036

Short-Term

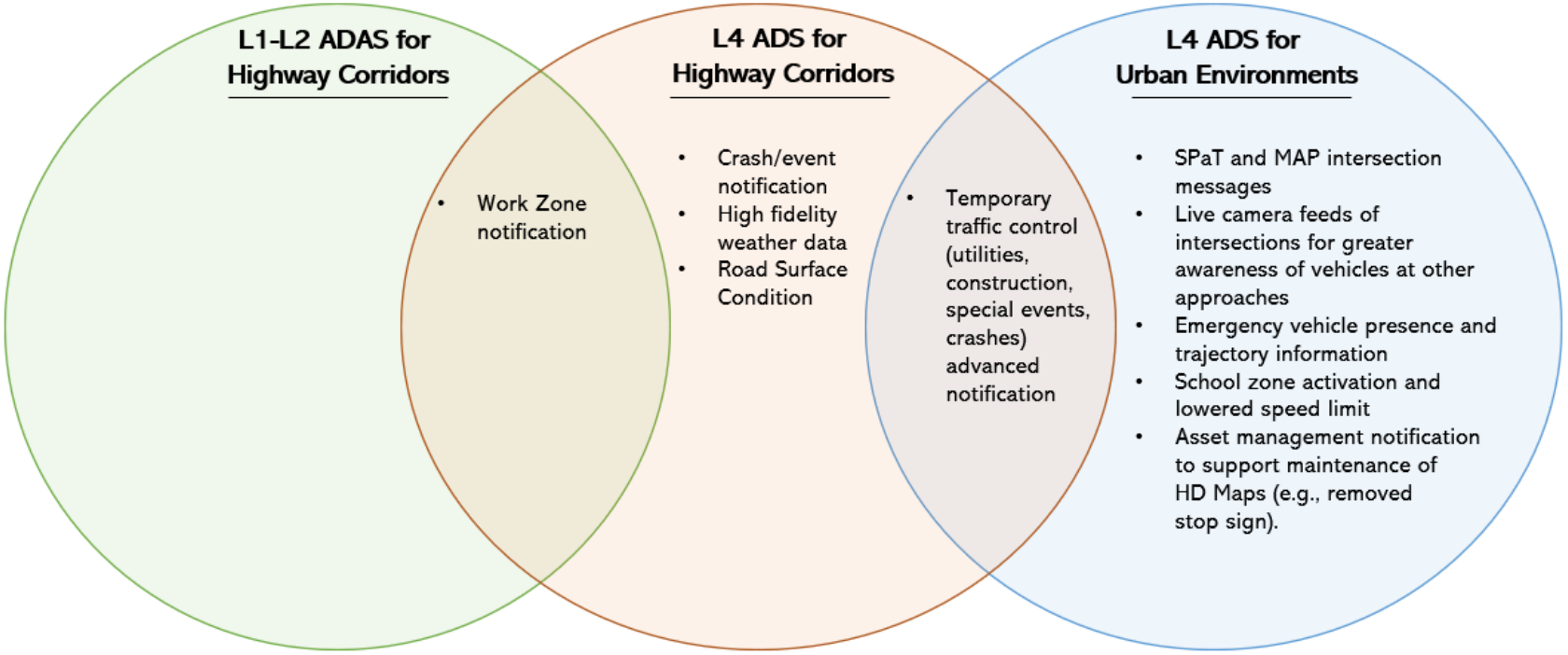
- V2X deployed on **20% of National Highway System**
- Top 75 metro areas have **25% of signalized intersections** V2X enabled

Long-Term

- V2X **fully deployed on National Highway System**
- Top 75 metro areas have **85% of signalized intersections** V2X enabled

Digital Infrastructure

- Cybersecurity
- Work Zone Information
- System Operations & Asset Data
- Tunnel Signal Repeaters
- Emergency Vehicle Presence & Routing
- Intersection Data
- Operations in School Zones
- HD Maps
- ITS / Roadside Equipment



Future Opportunities and Use Cases as Identified by AV Industry Representatives

WebResource

Web Resource Site for NCHRP 20-102(24)

Welcome to the AV Infrastructure Guide

This *AV Infrastructure Guide* was developed to increase the understanding of physical and digital infrastructure elements that influence automated vehicle (AV) technologies and provide Infrastructure Owner-Operators (IOOs) with strategies for implementing such improvements within their jurisdictions.

This WebResource is comprised of three sections:

- Background | Project information, common definitions, and AV system components
- Recommendations | Recommendations for tructure elements that influence AV operation and justification for recommendations

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Web Resource Site for NCHRP 20-102(24)

HOME | PROJECT INFORMATION | INFRASTRUCTURE RECOMMENDATIONS | IMPLEMENTATION STRATEGIES | REFERENCES

Search the W

- PROJECT INFORMATION
- COMMON DEFINITIONS
- AV SYSTEM COMPONENTS

to be completed in Task 7.

NCHRP 20-102: Impacts of CVs and AVs on Transportation Agencies

The NCHRP 20-102 program was established in 2015 to perform research supporting critical issues for infrastructure owner-operators (IOOs) related to the development and deployment of connected vehicles (CVs) and automated vehicles (AVs). As of 2024, more than thirty research projects have been completed or are in the process of being completed in the areas of policy, planning, infrastructure, and modal issues.

Task #24: Infrastructure Modifications to Improve the Operational Conditions of AVs

The purpose of this project, NCHRP 20-102(24), is to evaluate infrastructure requirements for the operational design domain (ODD) of driving automation systems and recommend strategies for IOOs to maintain, repair, replace, or add infrastructure elements to foster safer and more reliable operation. This research is intended to provide clear and concise recommendations for infrastructure investments that would advance the safe and efficient deployment of AVs.

Research Methodology

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Search the Website

- JUSTIFICATION FOR RECOMMENDATIONS
- INFRASTRUCTURE RECOMMENDATIONS

Infrastructure Recommendations

Physical infrastructure can limit the use of AV technology due to inconsistencies in design, placement, and maintenance of traffic control devices. In some cases, Roadway Digital Infrastructure paired with connected vehicle technology, can serve as an enabling technology that may help overcome difficult to remedy challenges associated with physical infrastructure and complex driving environments.

The following categories of Infrastructure Recommendations were identified, and a summary of each is provided in the sections below.

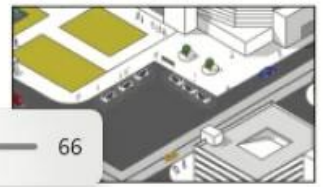
Categories of Infrastructure Recommendations


Pavement Markings


Roadway Surface


Traffic Signs


Traffic Signals



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We want to hear from YOU!

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Questions?

Thank you!

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Share your feedback