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Automated Vehicles Symposium

Impacts of Automated Vehicles (AVs) on Highway Infrastructure

July 18, 2019

Project Information

- Funded by FHWA Office of Infrastructure R&D
- Information in this presentation is for discussion purposes only
- Final products from research are expected in late 2019

Project Overview

GOAL

To develop practicable documentation and webinars to educate and inform DOT stakeholders about AV-related infrastructure needs.

OBJECTIVES

1) To assess and understand the demands and potential impacts of AVs on our current & future infrastructure assets.
2) To guide and assist DOTs on how to determine their “Readiness” for AV use on its highways.

Session Facilitators

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Road Infrastructure Inc.

Les Brown
ICF

Session Agenda (4 – 6 PM)

- **FHWA Introduction (5 minutes)**
- **Project Overview (5 minutes)**
- **Setting the Stage (10 minutes)**
- **Discussion of Impacts on Infrastructure Categories (70 minutes)**
  - Traffic Control Devices
  - TSMO and ITS
  - Multimodal infrastructure
  - Physical Infrastructure
- **Readiness Actions (20 minutes)**
- **Wrap Up (10 minutes)**

Session Purpose

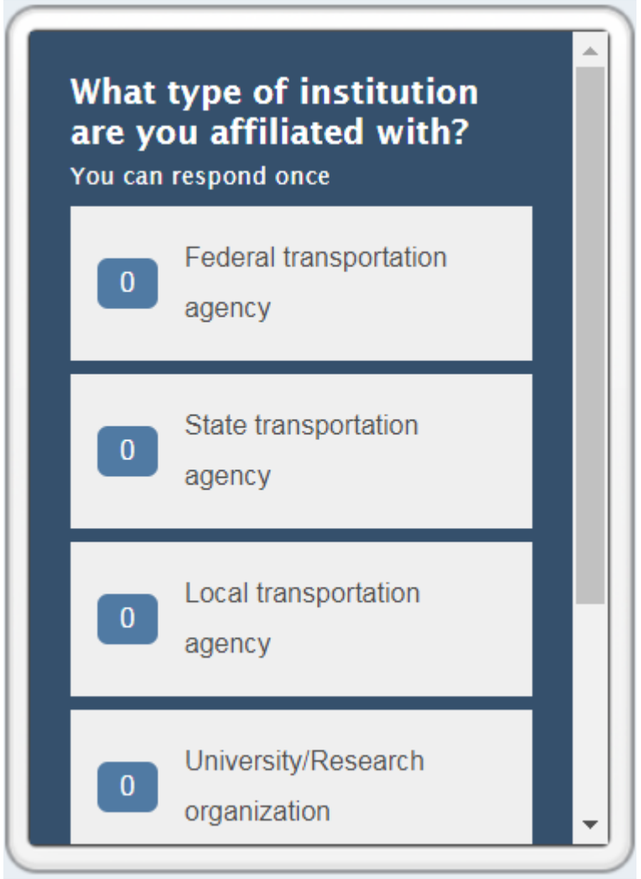
- **Share what we have learned from AV Industry & AASHTO Maintenance**
  - Now – priorities for today
  - Future – thoughts about the near-term future (in the next 10 years)
  - Readiness – assessing infrastructure readiness
- **Gather feedback in four functional areas of infrastructure**
  - Traffic control devices
  - TSMO/ITS
  - Urban multimodal
  - Physical infrastructure (pavements, bridges, and culverts)
- **Obtain your feedback**
  - Support
  - Concerns
  - Contributions
  - Questions.

Connecting to Wi-Fi

- WiFi Name: AVS2019
- Password: TRI

Poll Everywhere

- Using Poll Everywhere Tool throughout the session
- Submit responses on your mobile device at PollEv.com/deepakgopala832 *or* text DEEPAKGOPALA832 to 22333 once to join.



What type of industry best describes you?

Road Industry: Agency

Road Industry: Consultant/Contractor

Road Industry: Supplier/Manufacturer

Road Industry: Other

Auto Industry: OEM

Auto Industry: Supplier Manufacturer

Auto Industry: Other

None of the Above

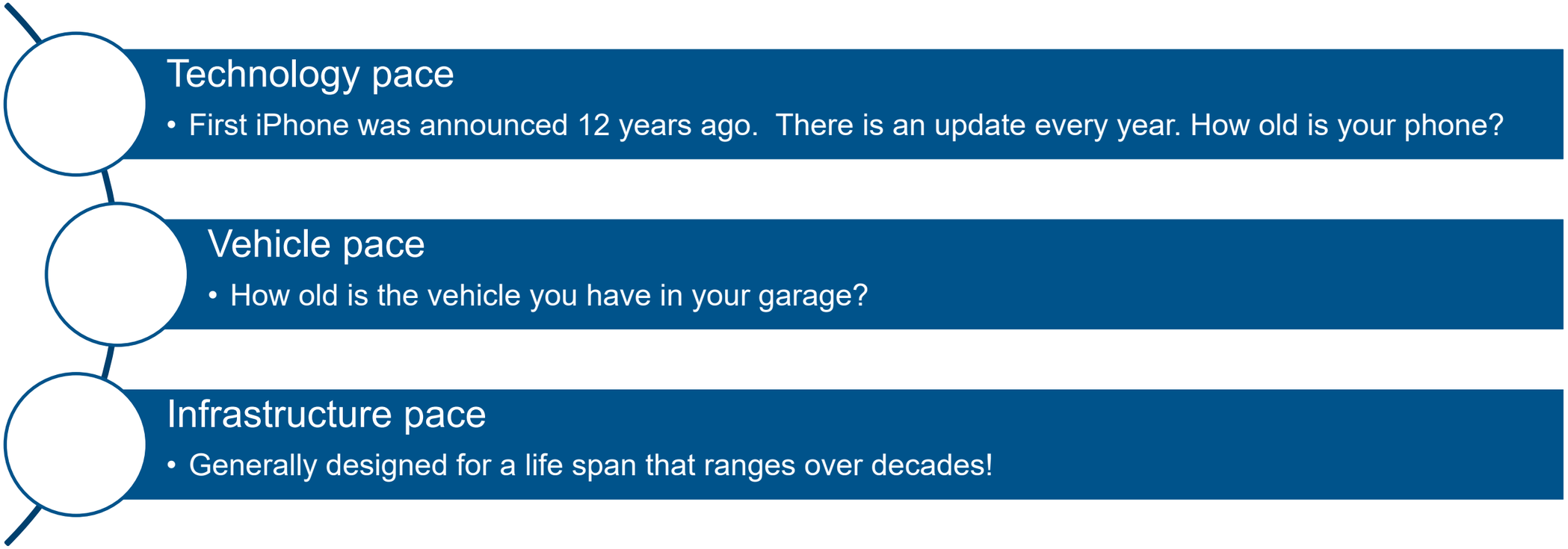
Setting the Stage

No Rush…Mixed-Fleet

- There are about 250,000,000 cars in the US
- By 2030, there will be close to 100,000,000 cars in the US with some automation (adaptive cruise control, lane departure warning, lane keep assistance, etc.)
- Level 2 cars are only recently available (Super Cruise in the Cadillac, AutoPilot in the Tesla, etc.)
- Audi has a Level 3 vehicle but not in the US
- Most car companies say they will have a Level 4 vehicle before 2030 (they don’t say if it will be available for the consumer to purchase)
- The average age of a vehicle in the US is almost 12 years
- It will take decades for significant US fleet penetration

Pacing the Industries

- **Can the highway infrastructure industry keep up with the pace of technology and vehicle automation?**



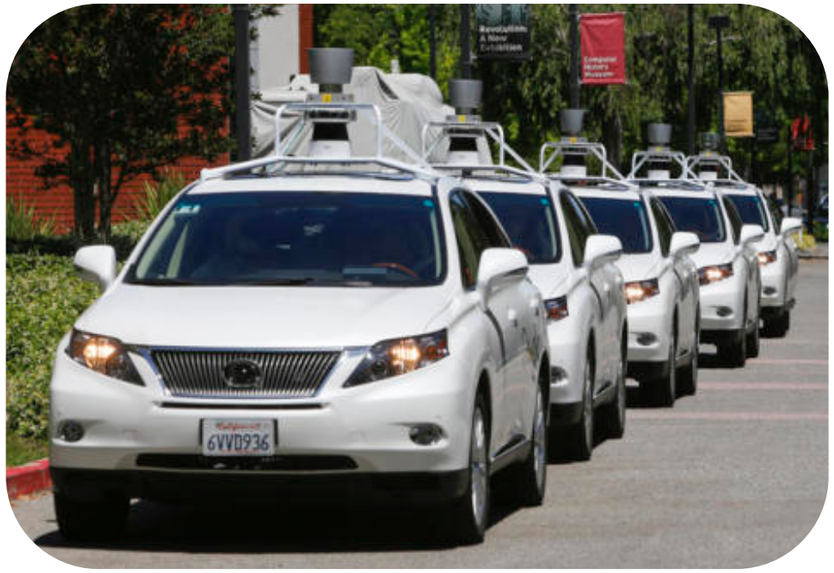
How Can the Highway Infrastructure Prepare?

- **Design driver has evolved and will continue to evolve**
  - Highway standards were initially developed with young(ish) driver performance data and low(ish) speeds
  - Highways now designed for the “older” drivers and speeds up to 85 mph

- **What is the next design driver?**
  - Vehicle sensors of <u>today</u>
    - Sensors that provide Level 1 and Level 2 automation
    - Low-risk investment for infrastructure owners and operators (these sensors are on current vehicles, will be on future vehicles, and will be on the road in increasing numbers for decades to come)
    - Sensor packages for Level 4 and Level 5 automation are not mature and vary by car company
  - Understanding how vehicle sensors interact with the highway infrastructure

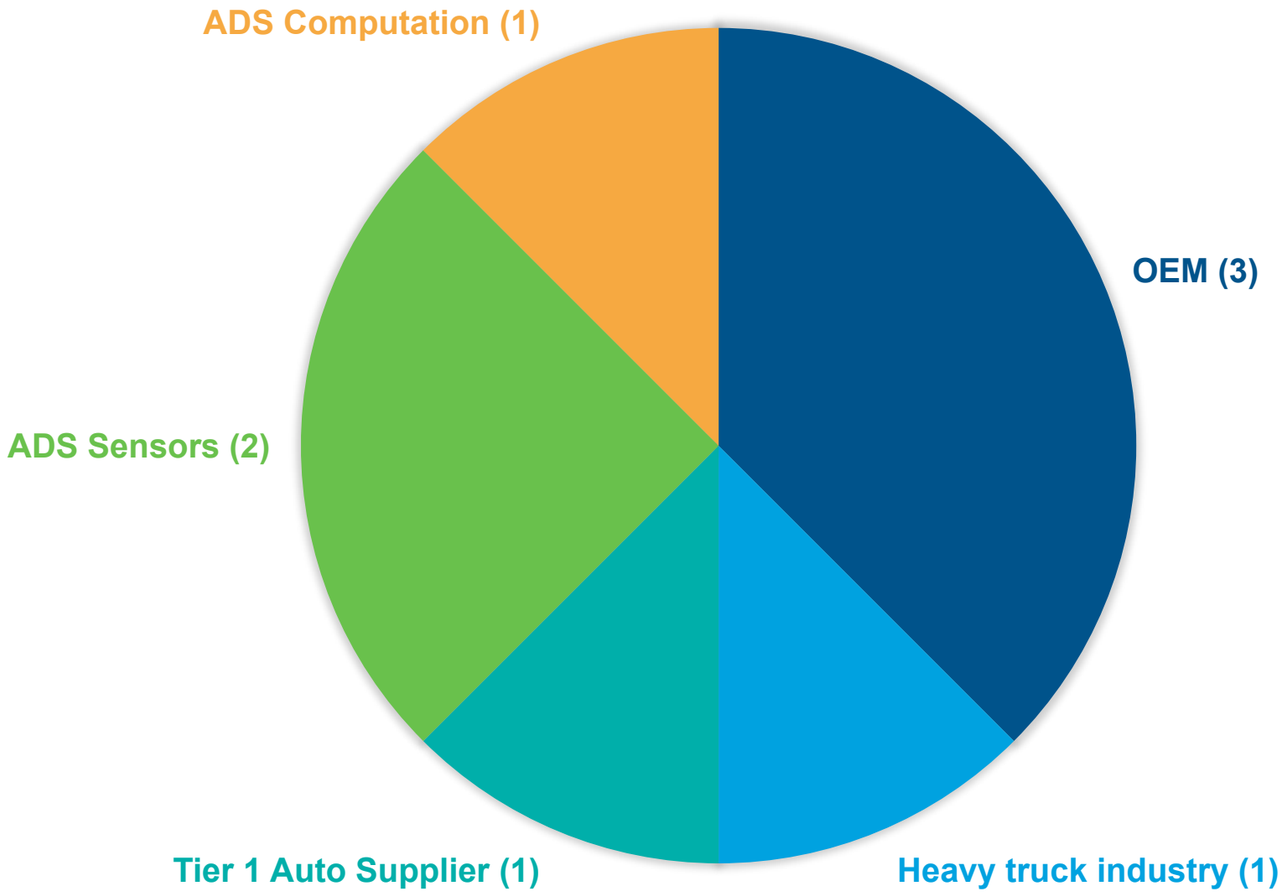
Research Questions

What are the problems today for AV testing, deployment, operations?



What are the risks and opportunities with widespread AV use in the future?

AV Industry Interviews



AV Industry Interviews: Key Observations

Implications of Sensor Evolution	• Rapid evolution and regular maintenance needs of sensors favors fleet operations in the near-term and presents challenges to future proofing infrastructure.
Quality and Uniformity of Physical Infrastructure	• Physical infrastructure should be well-maintained and consistent, especially regarding road markings and signage.
Digital Information Standards	• Digital information relayed to AVs should be standardized, secure, and specific to AV operational challenges (e.g., work zone related issues).
Urban Fleet Operations	• Urban fleet operations will be an important early application of AV and will offer near-term and non-traditional partnership opportunities between fleet operators and IOOs.

Key Observations (cont.)

Operational Design Domains	• OEMs are responsible for defining their operational design domain (ODD) and assume ultimate responsibility for safe operation within the ODD regardless of IOO actions.
Connectivity Between Vehicle and Infrastructure	• CV applications such as V2I can alert AVs on the presence of humans, however, industry is not relying on IOO support and is skeptical that V2I deployments will occur widely.
IOO Role of Traffic Systems Management and Operations	• AVs may exacerbate congestion in the short-term, making it increasingly important for IOOs to implement advanced traffic systems management and operations strategies.
Freight	• Freight is an early and incremental adopter of lower-level AV with its own path to deployment.
Governmental and Institutional Issues	• Clear guidance and policies are needed at the Federal level, while interagency and intergovernmental coordination are needed at the State and local levels.

Discussion of Infrastructure Impacts

Infrastructure Categories and Definitions

Highway Infrastructure Categories

Physical Infrastructure	Traffic Control Devices	TSMO and ITS Infrastructure	Urban Multimodal Infrastructure
Pavements, Bridges and Culverts	Pavement Markings, Traffic Signs, Traffic Signals, Temporary Traffic Control, Roadside Hardware	ITS Roadside Equipment, TSMO Strategies, TSMO Systems	Bicycle, Pedestrian, and Transit Infrastructure, Curb Space

Category 1: Traffic Control Devices (TCDs)

- Pavement Markings
- Traffic Signs
- Traffic Signals
- Temporary Traffic Control
- Roadside Hardware

Recent TCD Clues

- **January 2018 – FHWA ADS Request for Information (RFI)**
  - Greater uniformity and quality in road markings and other TCDs would enable automation
- **October 2018 – USDOT Automated Vehicles 3.0**
  - Quality and uniformity of road markings, signage, and other TCDs support safe and efficient driving by both human drivers and automated vehicles.
- **December 2018 – FHWA National Dialogue Outcome**
  - Highway infrastructure standards should be updated to respond to AV technology
- **April 2019 – AV Industry Interview Takeaway**
  - Uniformity and maintenance of physical Infrastructure: Physical infrastructure should be consistent and in good-state-of repair, especially with regard to road markings, signage, and potholes

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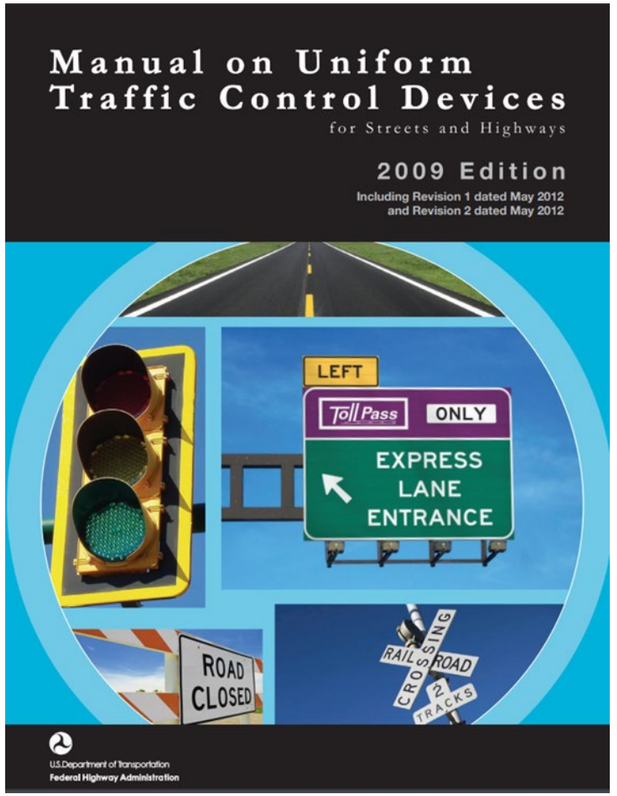
Let’s get Technical

- **Defining details that DOTs can use**
- **National Committee on Uniform Traffic Control Devices – Connected-Automated Vehicle Task Force**
  - Engaged Experts
  - Reviewed Literature
  - Developed Strawman
  - Surveyed and Coordinated with Stakeholders
    - AASHTO
    - Auto Alliance
    - Automotive Safety Council
    - Machine Vision Developers
    - ATSSA
  - Developed draft MUTCD language



Key TCD Areas

Uniformity

- Uniform applications - most common challenge
- Pavement markings are the highest priority for today's vehicle technologies, which are building blocks for tomorrow's more fully automated vehicles
- Temporary traffic control devices, signs, signals, multimodal

Design / Quality

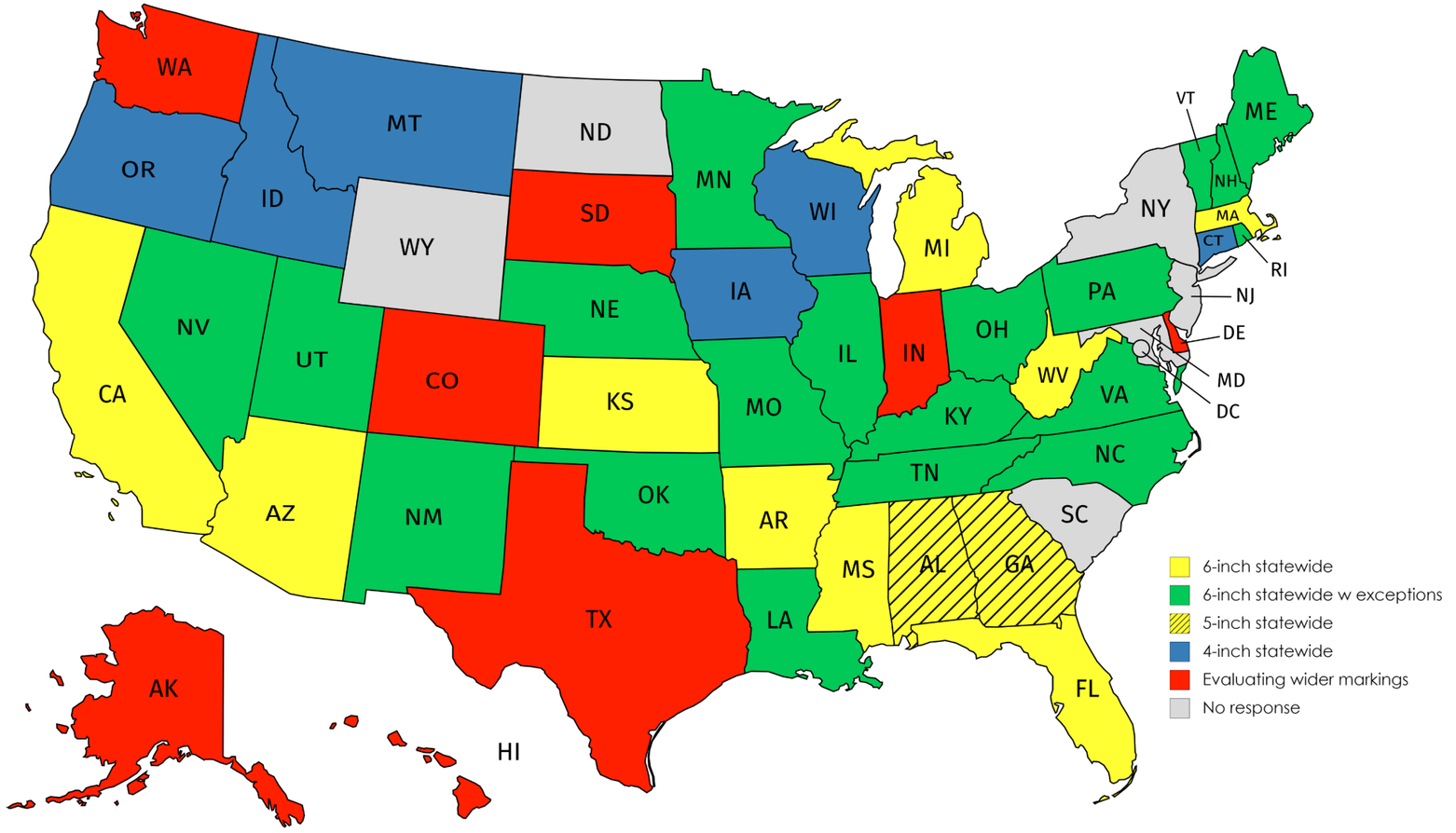
- Durable markings that remain visible in wet conditions, low-sun conditions, high-glare conditions, etc.
- TCDs compatible w machine vision systems (fonts, symbols, LED refresh rates, DMS signs, signal head photometrics, etc.)

Maintenance

- Maintenance criteria for machine vision systems

Compliance with MUTCD ≠ Uniformity

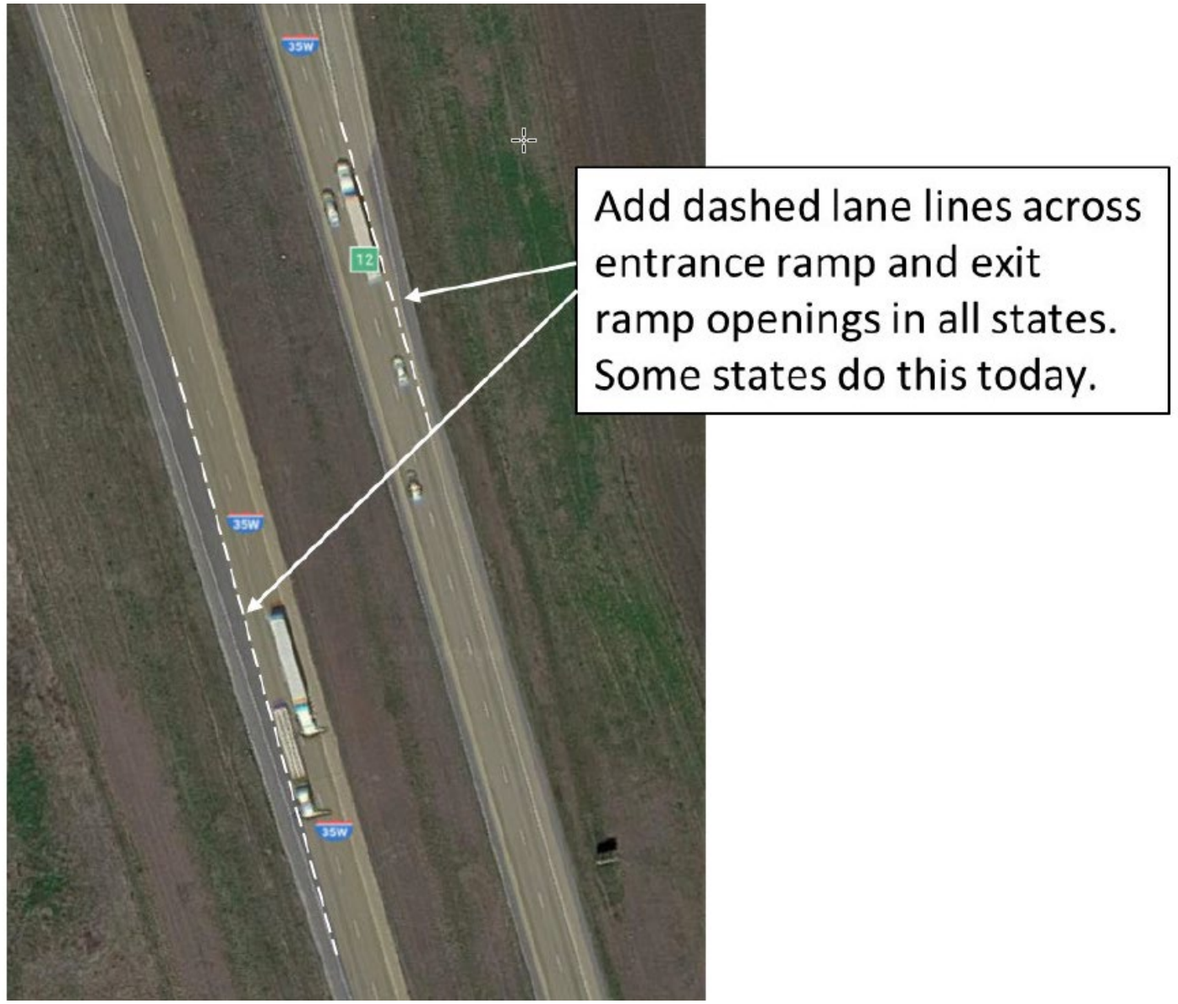
- MUTCD is silent on certain issues (such as contrast marking patterns)
- MUTCD allows flexibility in other areas (such as use of dotted lane line extensions along entrance and exit ramps)
- US map shows state DOT policies for pavement marking width



AASHTO CTE Survey Results (January 2019)

Examples of Auto Industry Input

- TCD uniformity “interests” identified through various engagements with auto industry representatives, companies, and associations.
- Example shown here where Google Earth image was annotated with “interest”



Examples of Auto Industry Input

- Another Google Earth image annotated showing an “interest” to use contrast markings on light colored pavements

Pavement Markings (now – good for human drivers and AV technologies)

- Use 6-inch wide longitudinal lines on freeways and interstate highways
- Use 6-inch edge lines on roadways with posted speeds > 40 mph
- Use dotted edge line extensions along all entrance and exit ramps
- Include Chevron markings in gore areas
- Use continuous markings at the beginning of work zones and in all lane transitions
- Eliminate the use of Botts Dots as a substitute for markings
- Use contrast markings on light colored pavements
- Use skip lines of 10-15 ft with a maximum gap of 25-30 ft
- Use arrows shapes approved in the FHWA Standard Highway Signs document

State Practices are Evolving

Staying in Your Lane Just Got Easier

Wider, Brighter, Longer-Lasting Road Striping To Help Drivers Today, in Future

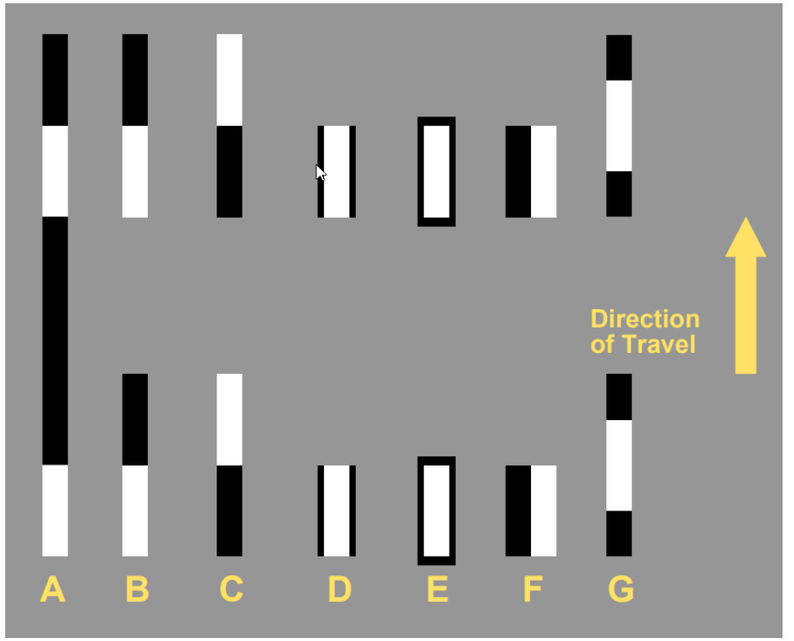
Caltrans' new, 6-inch-wide, highly reflective road striping was introduced on Interstate 80 through Sacramento as part of a statewide effort to restripe the 50,000-plus lane miles of state highway system in the next decade.

Motorists in many areas will notice the difference that the higher-profile striping makes on their driving experience. The new road demarcation lines, which consist of tape or thermal plastic embedded

"The new striping, with its wider and brighter profile, is expected to enhance safety for older drivers and truckers, and in challenging conditions such as rain. It also will be a better roadway guide for autonomous vehicles. Caltrans has consulted with auto manufacturer Tesla and Google, two major players in the autonomous vehicle industry, about the striping changeover."

Pavement Markings (later)

- Determine most effective contrast markings pattern for light colored pavements
- Determine most effective Chevron markings pattern for gore areas
- Tighten delineation standards of special lane assignments such as HOV/HOT lanes, bike lanes, transit lanes, etc.
- Evaluate daytime visibility performance metrics that correlate to machine vision and human vision capabilities (think of a metric like retroreflectivity but for the daytime conditions)
- Evaluate marking performance with latest technologies such as active cameras, LIDAR, and high-resolution radar.



Contrast Marking Patterns in the US

Carlson et. al. FHWA/TX-07/5008-2

Traffic Signs: Issues Identified

Vegetation management	• If the sign is occluded for a human driver, it is occluded for automated vehicle sensors too
National uniformity	• Agencies have developed their own signs
Speed limit signs	• Should be clearly associated with the specific roadway and/or lane
Symbols versus text	• Auto industry prefers symbols
Retroreflection	• “Good’ retroreflection is often cited but not quantified
Electronic signs flicker rate	• Illuminated portion of digital signs should have a standard refresh/flicker rate; LED refresh rates should be > 200 Hz for easier camera detection
Digitizing	• Digital database of sign type and placement that enhances role of in-vehicle data and mapping that might mitigate the need for machine-readable signage in the future (currently being proposed by VDOT)

Traffic Signals: Issues Identified

Consistency of Traffic Signal Placement	• With respect to approach lanes and horizontally aligned traffic signal heads.
Uniformity	• In terms of lane direction guidance (some agencies prefer to use green and red arrows, some don't use arrows as often, and some use flashing arrows while other do not).
LED traffic signals	• Creates unique challenges related to the frequency that they operate at (variability in the hertz of the displays).
Relevancy of the traffic signal head	• This topic pertains the lane(s) that the traffic signal is intended to provide control traffic information to. In some countries, a small arrow is placed above the traffic signal head to minimize confusion.

Temporary Traffic Control: Issues Identified

Standard signing

- At a fixed distance approaching the work zone and at the end of the work zone.

Traffic lanes

- Through the work zones should be unambiguous.

Vertical panels, tubes, and other channeling devices

- At least 8-inch wide with retroreflective material for reliable machine detection in all weather conditions

Markings entering the work zone and through lane shifts

- Need to be made with highly visible and continuous materials, not intermittent buttons and reflectors.
- The auto industry has often suggested the use of orange markings to delineate the vehicle path through a work zone. Orange markings have been tested by Wisconsin DOT and are currently under evaluation in Texas.
- Maximum spacing for vertical work zone devices need to be determined.

Roadside Hardware: Issues Identified

Concrete Walls

- Such as dividers should be marked with highly reflective markers, especially in the beginning section to enhance the visibility.

Barrier Contrast

- The barrier should provide high contrast from the adjacent road surface.

Steel-rope-barriers

- Are less visible than steel-beam-barriers by computer vision. Steel-beam-barriers or concrete walls with reflective markings are preferred.

TCDs: Feedback from AASHTO Workshop

- Understand that markings are a priority but more funding is needed to improve marking programs (higher standard of care including performance and maintenance).
- Some agencies are beginning to form internal teams to study how they can strategically support AV deployment.
- Some states are already making changes to their pavement marking polices to support AV deployment along with expected safety benefits for human-led vehicles.
- What can agencies do during inclement weather conditions (snow and ice) to support AV deployment?
- Can AV industry share data to help manage the infrastructure?

Do you agree or disagree that IOOs should prioritize changes to pavement marking practices to support AV deployment?

Strongly Agree

Somewhat Agree

Neither Agree or Disagree (Neutral)

Somewhat Disagree

Strongly Disagree

Do you agree or disagree with the recommended changes to pavement marking practices? Please briefly explain.

Top

What other near-term changes to the TCD infrastructure would best support AV deployment?

Top

Source: USDOT

- ITS Roadside Equipment
- TSMO Strategies
- TSMO Systems

Category 2: TSMO and ITS

Source: FHWA

TSMO and ITS: Issues Identified

ITS Roadside Equipment

- Need for SPaT and map data as early use-cases
- Significant challenges for AVs to read LED signs (including VSL and VMS)
- Barrier road crossings (e.g., tolls) can impede AVs from providing continuous eyes-off/hands-off travel

TSMO Strategies

- Need for TSMO strategies may be greater in the near-term
- Demand management strategies may become more critical to manage for reliability (e.g., pricing)
- New performance measures may be needed

TSMO Systems

- Will require new or upgraded systems to ingest and manage large amounts of CAV data.
- New data management framework will require a clearly defined data governance structure
- Agency risks on data-sharing agreements, privacy policies, and IT/network security.

40

TSMO/ITS: Feedback from AASHTO Workshop

- Need to develop data sharing agreements good for all
- Digital mapping standards – necessary?
- DSRC – 5G dilemma slowing down CV deployments
- How can IOOs work with AV industry to reduce the need for roadside ITS equipment needs (and maintenance) because of increased density of vehicle generated data

What near-term changes to TSMO/ITS infrastructure would best support AV deployment?

Top

Are there other impacts on the TSMO/ITS infrastructure that you're aware of?

Top

- Bicycle, Pedestrian, and Transit Infrastructure
- Curb Space

Category 3: Urban Multimodal Infrastructure

Source: : www.pedbikeimages.org/Ann McCrane

Bike-Ped and Transit: Issues Identified

- Need for robust AV detection algorithms in multimodal ODDs to understand pedestrian and bicyclist behavior.
- AVs must include redundancies to allow pedestrian detection outside clearly demarcated areas.
- Use of sensors/V2X technology to advance notify AVs about bicyclist/pedestrian presence.
- Intersection controls should have a pedestrian and bike only phase.

Bike-Ped and Transit: Issues Identified

- Need for surveys and road safety audits prior to AV implementation to ensure clear pedestrian ROW.
- Use of third-party data platforms that anonymize and aggregate to pinpoint hotspots for vulnerable road users.
- Mode separation can mitigate disengagements and boost the safety and confidence of vulnerable road users.
- Dedicated BRT lanes retrofitted with AV technologies for automated transit systems testing.

Curb Space: Issues Identified

- Need to ensure bicycle and pedestrian networks are not fragmented by curb-related changes.
- Use of tools to pinpoint high-volume ridesourcing passenger pickup and drop-off areas and urban goods delivery areas and inform redesign and reallocation of curb space to accommodate the most productive uses and minimize conflicts with other modes.
- Mobility hubs can support node-to-node travel (rather than door-to-door travel) to make more efficient use of curb space and encourage the use of shared modes.

Multimodal infrastructure: Feedback from AASHTO Workshop

- Vulnerable users needs
- Unique intersection designs such as roundabouts
- Complete streets increases maintenance costs

What near-term changes to urban multimodal infrastructure would best support AV deployment?

Top

Are there other impacts on the urban multimodal infrastructure that you're aware of?

Top

Readiness

Infrastructure AV Readiness Checklist

Freeways/Expressways

Expanded effort in preventative maintenance

- Addressing potholes, edge wear, rutting

Revisiting Pavement Marking Uniformity

- 6-inch width
- Dotted edge line extensions along ramps
- Chevron markings in gore areas
- Continuous markings for Work Zone tapers
- Eliminate Botts Dots as a substitute for markings
- Contrast markings on light colored pavements

Positioning Signs

- Minimize confusing speed limit signs along parallel routes

Improving TSMO Practices

- Greater standardization of active traffic management/dynamic management signage (like for Variable Speed Limits, Lane Controls, Work Zone Management)

Infrastructure AV Readiness Checklist

- **Other Highways**

Preventative Maintenance

- Potholes, edge wear, rutting

Markings

- 6-inch width on edge lines with posted speeds > 40 mph
- Continuous markings for Work Zone tapers
- Eliminate Botts Dots as a substitute for markings
- Contrast markings on light colored pavements

Improving TSMO

- Greater standardization of active traffic management/dynamic management signage (like for Variable Speed Limits, Lane Controls, Work Zone Management)

Infrastructure AV Readiness Checklist

Urban / Local Roads

Preventative Maintenance

- Potholes, edge wear, rutting

Markings

- Continuous markings for Work Zone tapers
- Eliminate Botts Dots as a substitute for markings

TSMO

- Equip intersections with SPaT and devices that can communicate the presence of vulnerable road users to vehicles
- Equip parking systems with V2I capabilities
- Greater standardization of active traffic management/dynamic management signage (like for Variable Speed Limits, Lane Controls, Work Zone Management)

Multimodal

- Adopt mode separation policies (e.g., Complete Streets)
- Anticipate growing curbside demand in site design, street design, and access management practices.
- BRT lanes retrofitted with AV technologies provide opportunities for automated transit systems testing

AASHTO Response to Readiness

- **How ready is your agency?**
  - Very ready 0 0%
  - Somewhat ready 8 15%
  - Neutral 13 24%
  - Unready 10 18%
  - Very Unready 23 43%

- **Common comments**
  - Lack or resources / funding
  - Needs not well defined
  - Striping inadequate
  - Lack of an understanding

What else is needed in an IOO checklist to support AV deployment?

Top

To what extent will AV deployment be affected by the pace of infrastructure adaptation?

Top

How ready are IOOs to support AV deployment?

Very Ready

Somewhat Ready

Neither Ready of Unready

Somewhat Unready

Very Unready

Please indicate why you believe IOOs are ready or unready to support AV deployment.

Top

What role does the condition of the infrastructure play in defining an ODD for a specific use case?

Top

What suggestions do you have to encourage deeper collaboration between the road and AV industries?

Top

Next Steps

- Review Literature **(completed)**
- Engage Stakeholders **(on-going)**
- Conduct AV Industry Interviews **(completed)**
- Develop Draft Findings **(completed)**
- Obtain Feedback **(on-going)**
  - Present, vet, discuss (workshops)
    - AASHTO Maintenance Conference, Grand Rapids, MI
    - TRB Automated Vehicle Symposium, Orlando, FL (tomorrow)
- Refine Findings **(next step)**
- Develop Techbrief **(future task)**
- Conduct Webinars **(future task, by EOY)**

Wrap-Up

- **For more information or follow-up discussions, contact:**

Dr. Abdul Zineddin, FHWA – Abdul.Zineddin@dot.gov

Thank you for your time and feedback!