Tightening National Traffic Control Device Uniformity to Support AV Deployment

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SASHTO Mtg.
Savannah, GA – Aug 2019

Road Infrastructure

FHWA National Workshops on AV Impact

- **AASHTO Maintenance Mtg, Grand Rapids, MI, July 17, 1 – 4 PM**

14	117	60	34%
Polls	Participants	Average responses	Average engagement

- **TRB AVS Mtg, Orlando, FL, July 18, 4 – 6 PM**

16	50	25	41%
Polls	Participants	Average responses	Average engagement

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Responses to Agency 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

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Recent Milestones

- **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 (on-going FHWA project)**
  - 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

Developing an Understanding

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Preparing the Highway Infrastructure

- **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 “high” speeds

- **What is the next design driver?**
  - Vehicle sensors that provide partial to full automated features
    - 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 unknown
  - Understanding how vehicle sensors interact with the highway infrastructure

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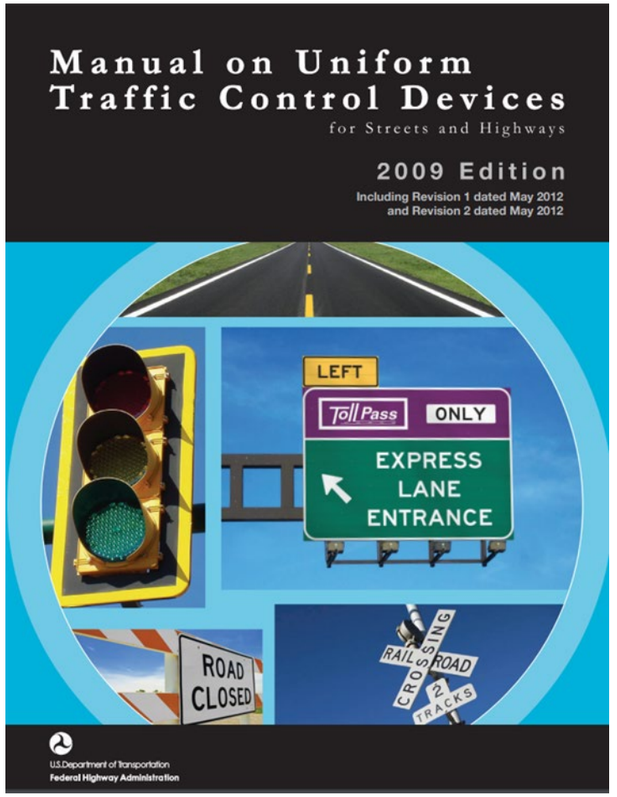
Efforts Underway in the US

- **Understanding practical information 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



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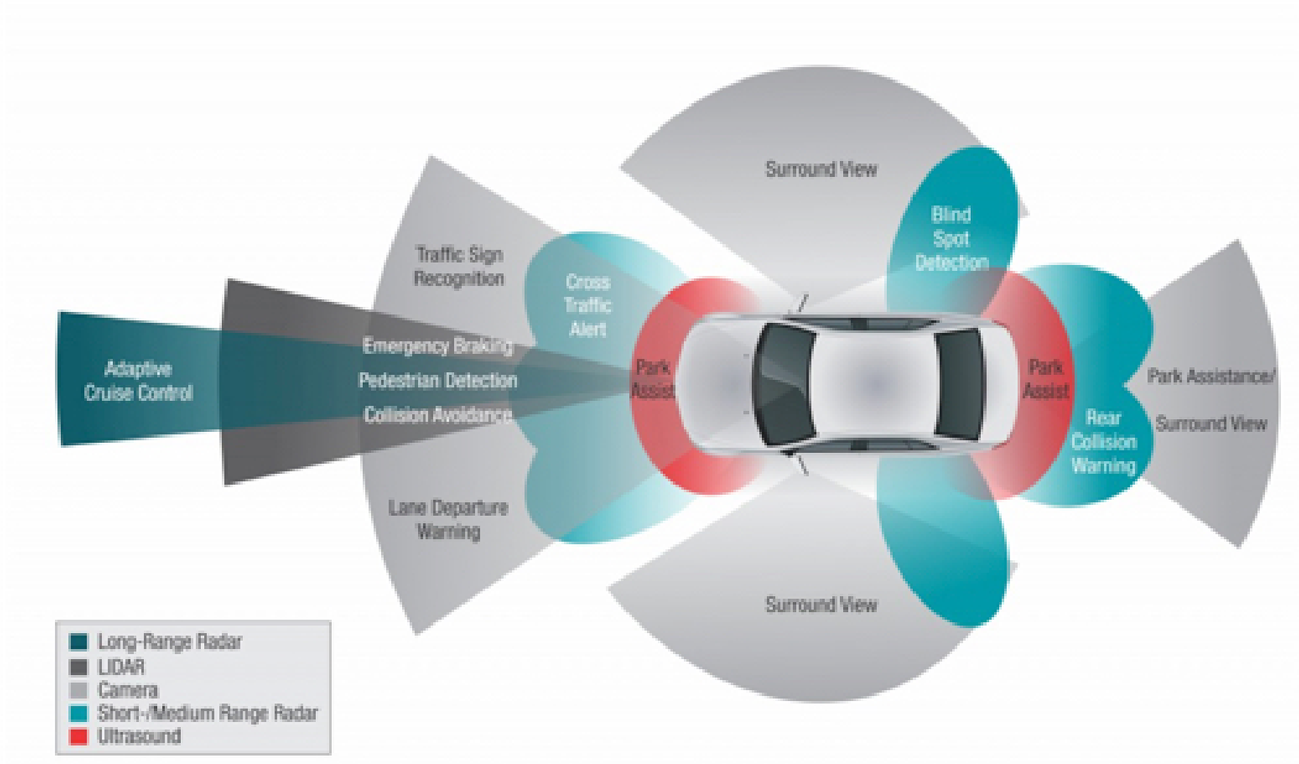
AV Sensors and Highway Infrastructure

- **Pavement markings are a critical link for safe vehicle automation**
- **Passive cameras (and software) used to**
  - Detect markings
  - Interpret markings
  - Laterally position vehicle
  - Confirm vehicle location



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Key Areas of Pavement Marking Needs

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

Design / Quality

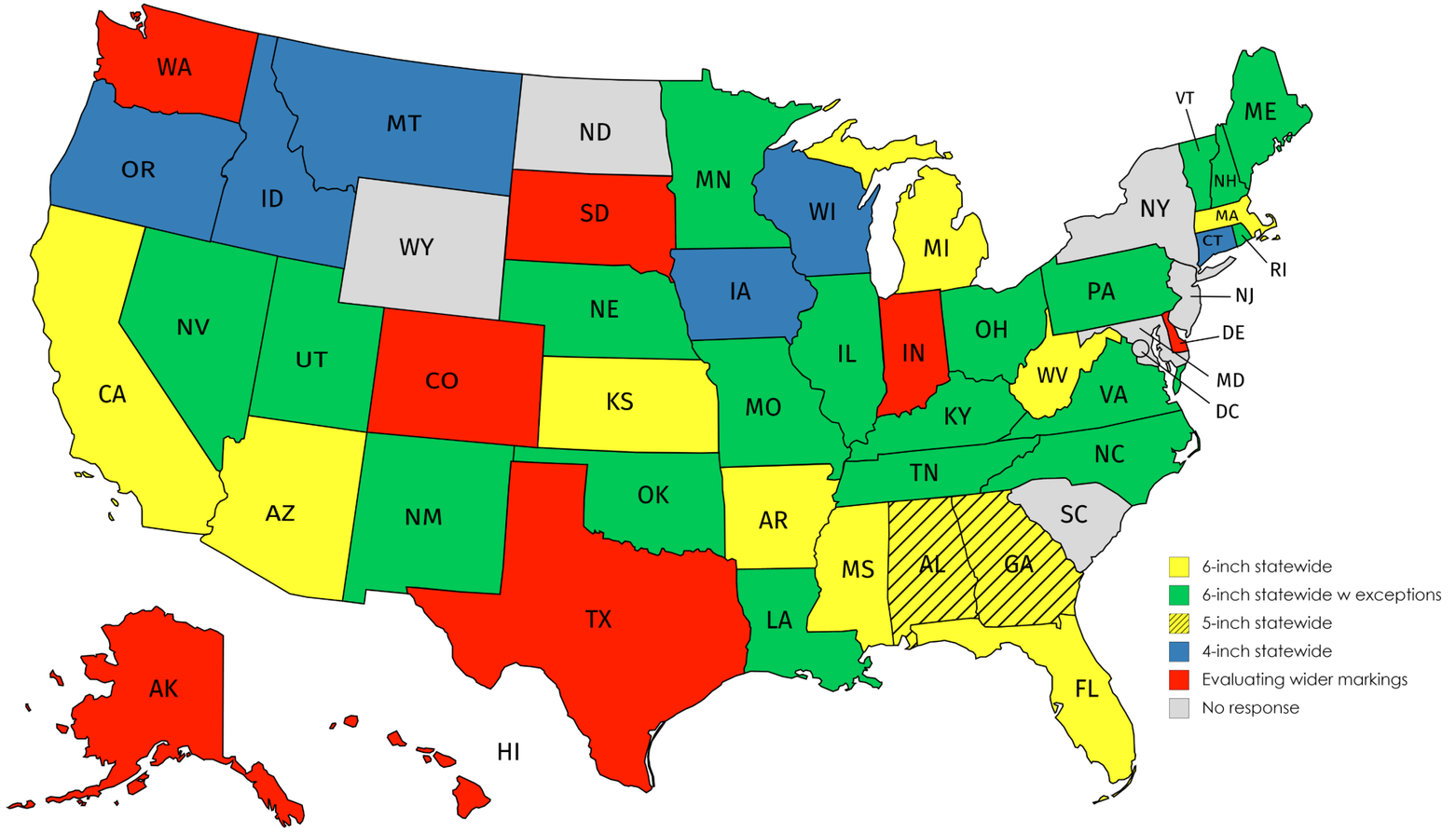
- Durable markings that remain visible in wet conditions, low-sun conditions, high-glare conditions, etc.

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)

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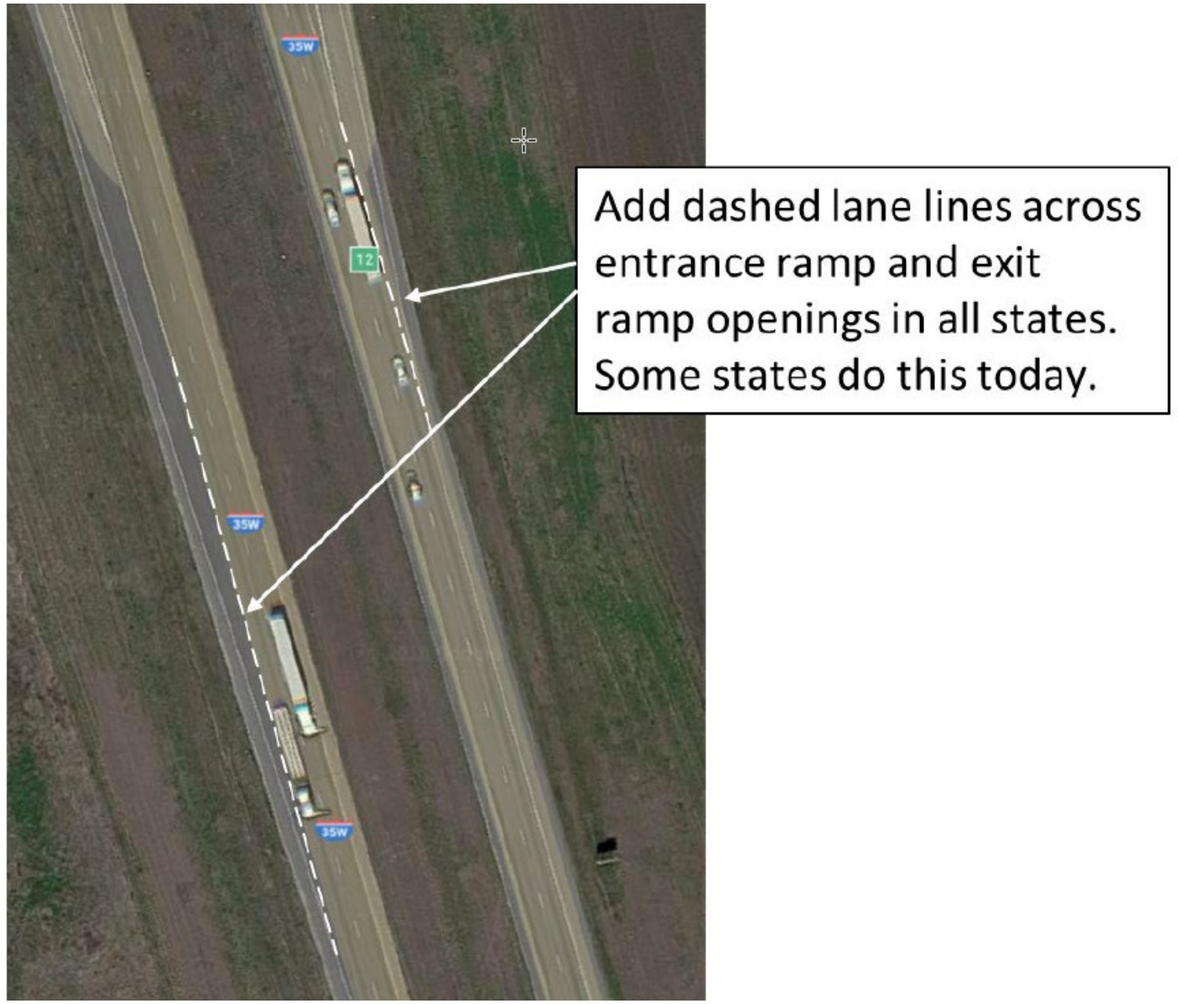
Examples of Vehicle Industry Input

- 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”



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Examples of Vehicle Industry Input

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

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

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

State Practices are Evolving

Caltrans®

Staying in Your Lane Just Got Easier

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

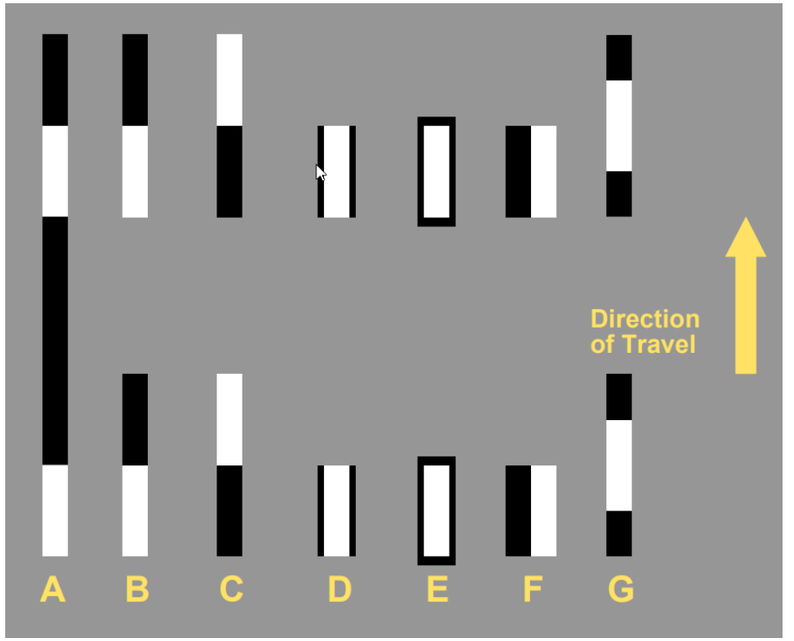
Caltrans' new, 6-inch-wide, highly reflective road striping was introduced on Interstate 80 through Sacramento as part of a statewide effort to restripe the 50,000-plus lane miles of state highway system in the next decade.

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."

More Work is Needed

- 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

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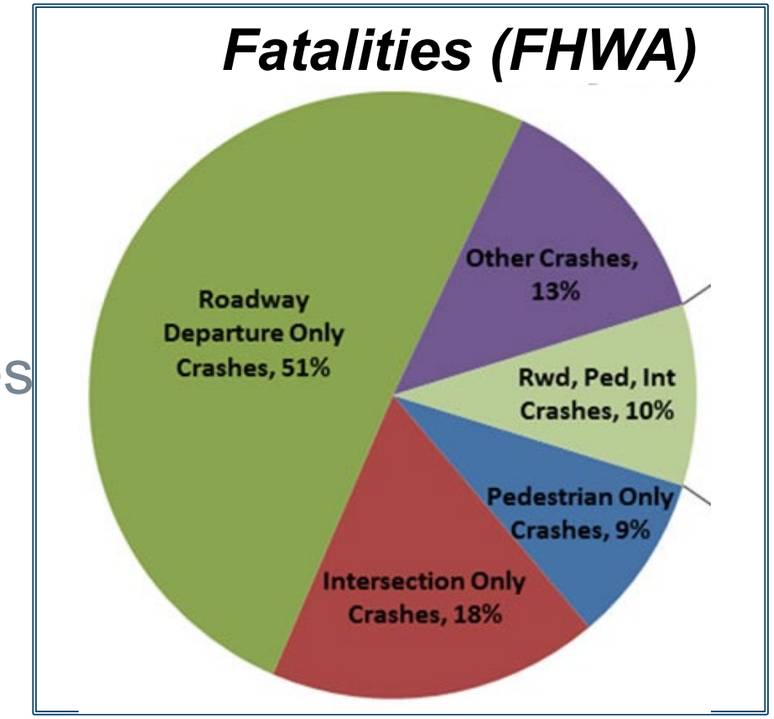
Safety Potential of Key ADAS Features

- **Lane Departure Warning (LDW)**
  - 9,020 fatal crashes (29% of all fatal crashes)
  - 21% of all injury crashes
- **Forward Collision Warning (FCW)**
  - 800,000 crashes (14% of all crashes) + 750 fatal crashes
- **Blind Spot Monitoring (BSM)**
  - 267,000 crashes + 280 fatal crashes



References:

- *Harper, C. D., Hendrickson, C. T., Samaras, C. Cost and benefit estimates of partially-automated vehicle collision avoidance technologies. Accident Analysis & Prevention, 95, 104–115. 2016*
- *IIHS, Status Report, Vol. 52, No. 6, August 23, 2017*

ADAS = Automated Driving Assist Systems

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Time to Get Your Roads Ready

- **Lane Departure Warning (LDW)**
  - 2020, standard on 40-80% of new car sales
  - 2025, standard on 70-99% of new car sales
- **Lane Keep Assist (LKA)**
  - 2020, standard on 10-24% of new car sales
  - 2025, standard on 30-73% of new car sales

J. Cicchino. Effects of lane departure warning on police reported crash rates. Journal of Safety Research, 66, 2018

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Markings for Machine Vision

- **Retroreflectivity (nighttime)**
  - Today's machine vision systems need less retro than the humans
  - FHWA finalizing minimum retroreflectivity levels for markings in 2019
- **Contrast (daytime)**
  - The contrast between the marking and the pavement should be 3:1
  - Most conditions provide adequate contrast without black markings
  - Concrete surfaces and other light colored pavements benefit from contrast striping
  - Still working on how to measure daytime contrast
- **Marking width**
  - 6-inch wide markings provide benefit in terms of detection under challenging visibility conditions (worn markings, low contrast, wet conditions, glare, etc.)

Questions?

Paul Carlson, Ph.D., P.E. | Road Infrastructure, Inc.

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- Chair, NCUTCD CAV Task Force
- Chair, SAE Infrastructure Task Force
- AASHTO CAT Coalition, Infrastructure-Industry Working Group
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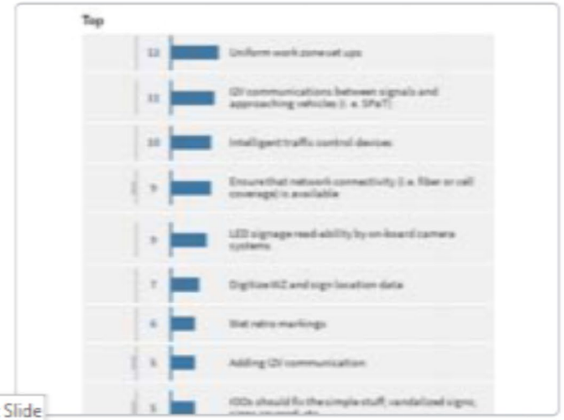
What other near-term changes to the TCD infrastructure would best support AV deployment?



Responses	Upvotes	Downvotes
Uniform work zone set ups	12	0
I2V communications between signals and approaching vehicles (i. e. SPaT)	11	0
Intelligent traffic control devices	10	0
Ensure that network connectivity (i.e. fiber or cell coverage) is available	10	1
LED signage read-ability by on-board camera systems	9	0
Digitize WZ and sign location data	7	0

54%

Engagement

36

Responses

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SAE AUTOMATION LEVELS[1]

0 No Automation

The full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems.

1 Driver Assistance

The *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*.

2 Partial Automation

The *driving mode*-specific execution by one or more driver assistance systems of both steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*.

3 Conditional Automation

The *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*.

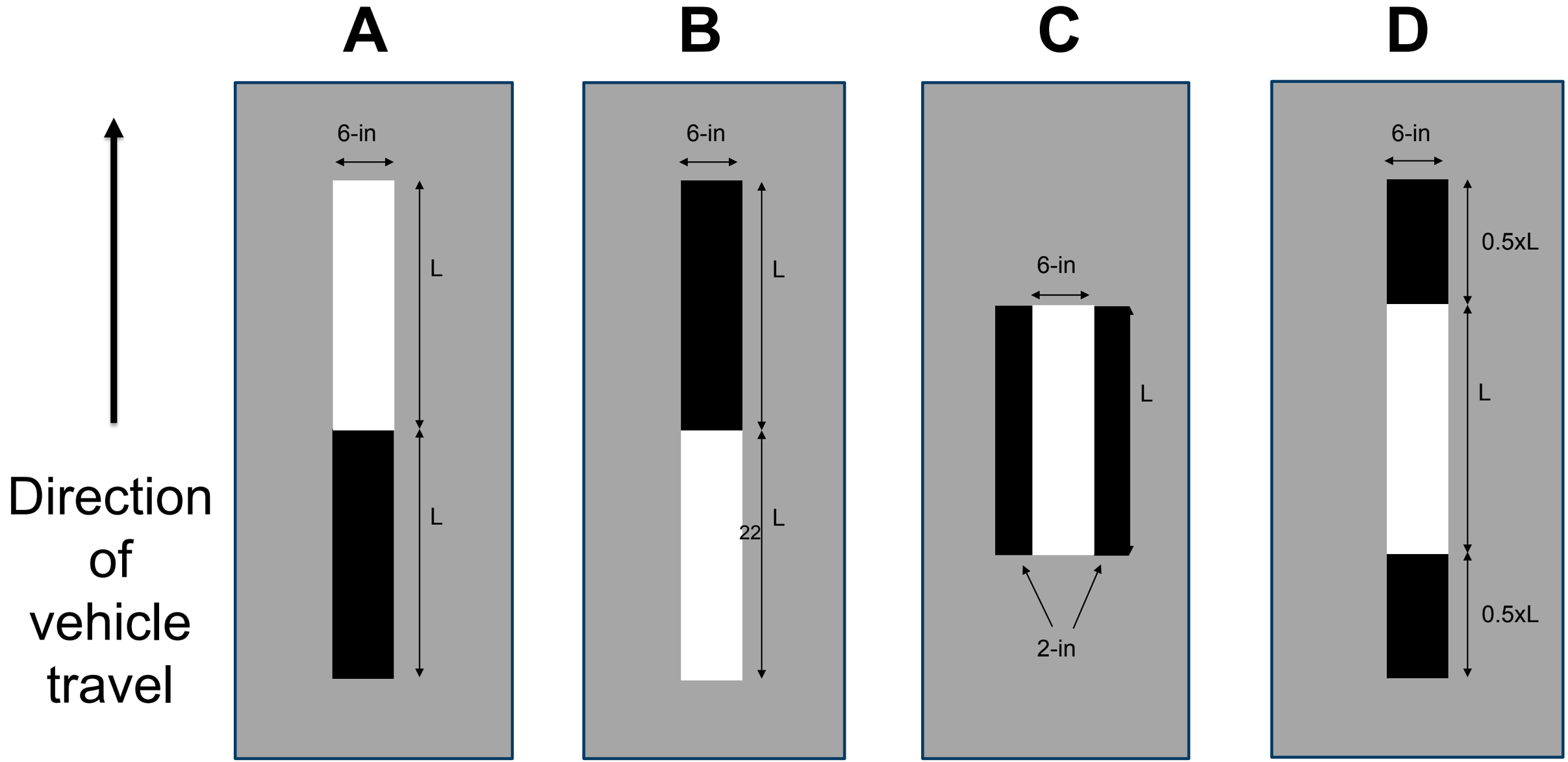
4 High Automation

The *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*.

5 Full Automation

The full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*.

1 SAE International, J3016_201806: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (Warrendale: SAE International, 15 June 2018), https://www.sae.org/standards/content/j3016_201806/.



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Lane Marking Contrast on Light-Colored Pavements

- Using the images on the following page, please complete the table by indicating your preference for each configuration.

	Configuration (see images on next page)			
	A	B	C	D
Acceptable	xxxxxx	xxxxxx	x	xxxxx
Preferred	xxxx	xxxx	xx	x
Not Acceptable			xxx	x

- Comments
  - C pattern might be very confusing. In some visibility conditions, the white markings are not visible, and the black is partly visible – this can cause a misleading detection where you detect only the left or right black pattern. In that case, the lane mark detected will be very inaccurate and may cause steering problems. Pattern B is more preferable than A due to the fact that the white segment appears before the black. Dirt like black tire skid marks may seem like a beginning of a dark lane mark.
  - Prefer A or B, and B over A –the white before the black.
  - A, B, & D are preferred/acceptable as long as the length of the black marking is not included in the gap length (see additional images for clarification on slides 11 and 12)