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TRANSPORTATION RESEARCH BOARD

Changing the Manual to Support Deployment of Automated Vehicles

August 18, 2021

1:00- 2:30 PM Eastern

@NASEMTRB
#TRBwebinar

PDH Certification Information:

- 1.5 Professional Development Hours (PDH) – see follow-up email for instructions
- You must attend the entire webinar to be eligible to receive PDH credits
- Questions? Contact Beth Ewoldsen at Bewoldsen@nas.edu

#TRBwebinar

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Providers Program. Credit earned on completion of this program will be reported to RCEP. A certificate of completion will be issued to participants that have registered and attended the entire session. As such, it does not include content that may be deemed or construed to be an approval or endorsement by RCEP.

RCEP

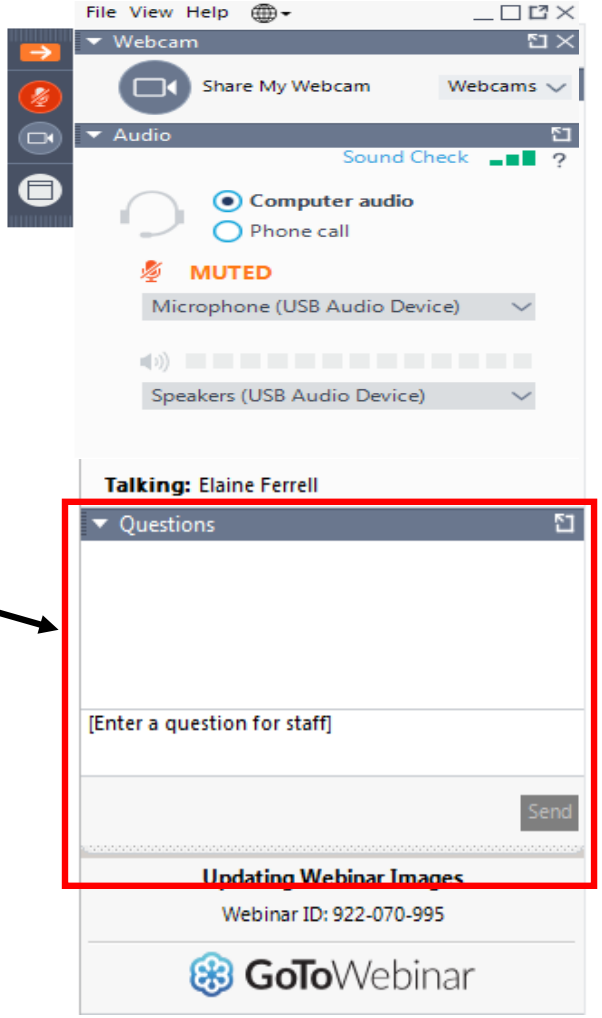
REGISTERED CONTINUING EDUCATION PROGRAM

Learning Objectives

- Identify how to prepare highways for safe AV development

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



#TRBwebinar

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TRB Sponsors

- **Traffic Control Device Committee (ACP55)**
  - **Chair: Dr. Tim Gates**
  - **https://www.mytrb.org/OnlineDirectory/Committee/Details/5173**

- **Vehicle-Highway Automation (ACP30)**
  - **Chair: Jane Lappin**
  - **https://sites.google.com/site/trbvehiclehighwayautomation/Home**

What is the NCUTCD - CAV JTF?

NCUTCD = National Committee on Uniform Traffic Control Devices

- Non-govt group with 21 sponsoring organizations
- Focuses on standards and guidelines for traffic control devices
- Submits recommended MUTCD changes to FHWA
  - 200+ submitted for 2009 MUTCD

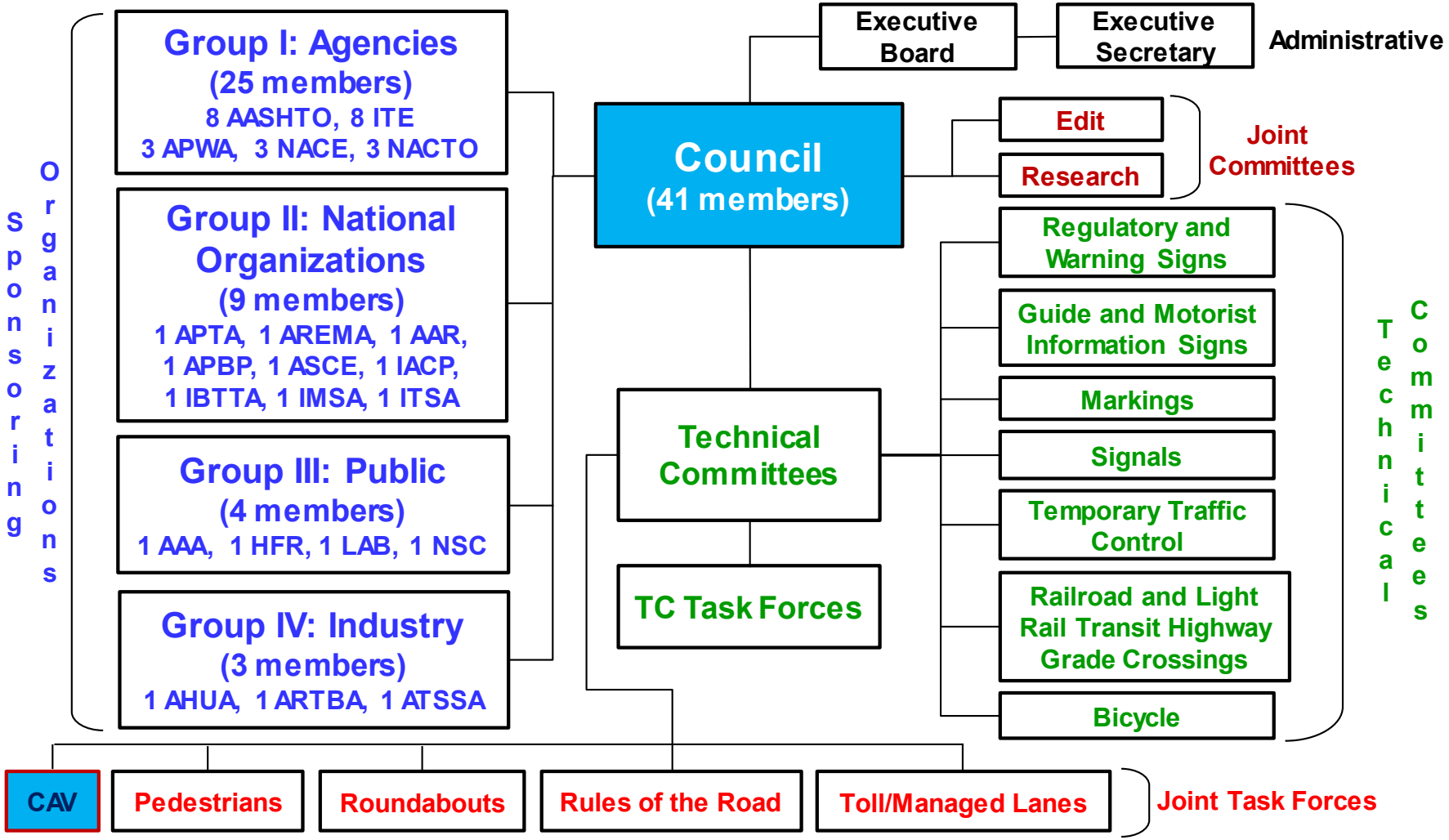
Website: ncutcd.org

NCUTCD strength: consensus-building process

CAV = Connected & Automated Vehicle

JTF = Joint Task Force

NCUTCD Structure



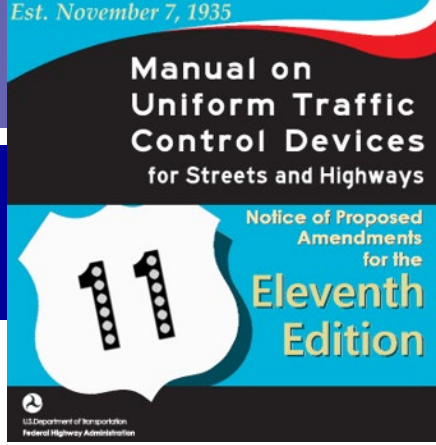
TRANSPORTATION RESEARCH BOARD

Changing the MUTCD to Support Deployment of Automated Vehicles

Background and Proposed Provisions Related to Automated Vehicle Systems

August 18, 2021

Kevin J. Sylvester, P.E., PTOE
Team Leader, Traffic Control Devices
Office of Transportation Operations



What can you expect?

- **Quick background on the MUTCD**
  - *What it is*
  - *How it gets updated*
  - *How content is established*

- **Highlight major proposed changes related to CAV**

But first, a few details…

- **The Notice of Proposed Amendments (NPA) is just that—a <u>proposal</u>**
  - *Currently analyzing public comments*
  - *Cannot predict timeline*
  - *Cannot predict future action*

The current MUTCD is <u>still</u> the national standard (2009 Edition, Rev. 2)

What is the MUTCD?

MUTCD \ˈem-yü-ˌtē-sē-dē\[1] *n* (ca. 1935): the national standard for traffic control devices on all roads open to public travel in the United States.

[1] Not \ˈmyüt-sid\, \ˈmət-sid\, or \ˈmət-kid\.

What is the MUTCD?

- A **human-centered, data-driven** safety and operational protocol
- **Effective** traffic control
- **Uniform system** of signs, signals, and markings
- **Ultimately, the MUTCD is about the road user**
  - Pedestrians
  - Bicyclists
  - Motorists

All with differing levels of abilities and limitations.

MUTCD – Statutory Authority

- **23 United States Code 109(d)[1]**

Law requires compliance,
"..*only in such [traffic control device] installations as will <u>promote</u> the safe and efficient utilization*" of streets and roads.

The MUTCD is codified in regulation at **23 CFR 655.603**

[1] ***Highway Safety Act*, 1966.**

What is a Traffic Control Device?

A traffic control device…

- Communicates with the road user
- About condition, direction, information
- Relevant to the travel task as you use the road
  - *Signs*
  - *Markings*
  - *Signals*
- And "promotes the safe and efficient utilization" of the roadway system

What is an *effective* Traffic Control Device?

An effective traffic control device[1]…

- *Fulfills a need;*
- *Commands attention;*
- *Conveys a clear, simple meaning;*
- *Commands respect from road users; and*
- *Gives adequate time for proper response.*

…from the perspective of the road user.

[1] **MUTCD, 2009 Ed., Sec. 1A.02**

What's behind the MUTCD?

- Promote **safety**
- **Data-driven**
  - Ensures balanced, objective approach
- Importance of **uniformity** <u>and</u> **flexibility**
  - Context matters
  - Ability to address unique situations while still accommodating the human factors

How does data feed the MUTCD to promote safety?
Independent research, official experimentation, all in the context of the human behavior of road users.

What is the MUTCD . . . *not* ?

- Not a street or highway design standard
- Not a comprehensive safety manual
- Not a policy or directive on how to use your roads and streets

MUTCD – The Amendment Process

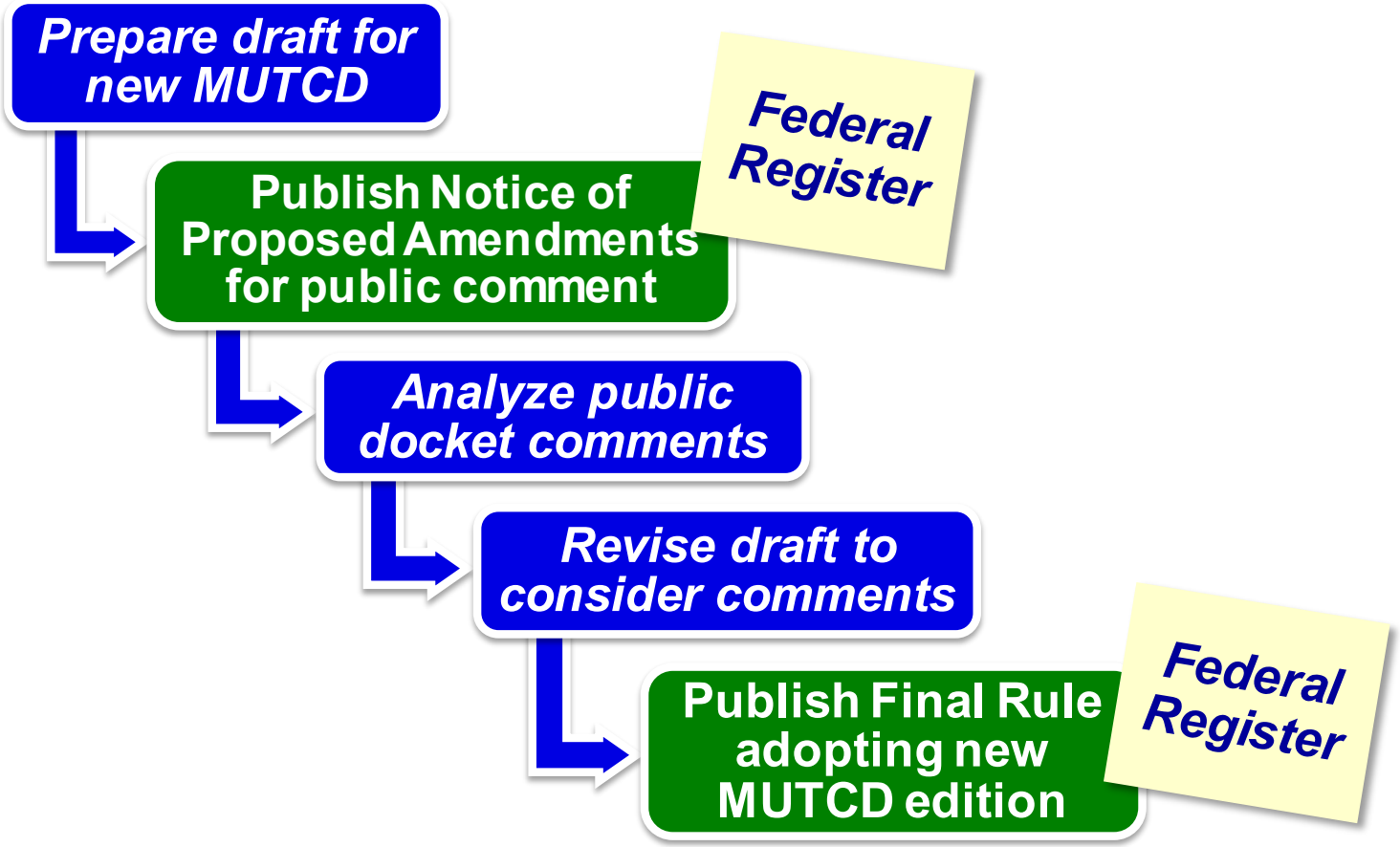
- **Why Rulemaking?**
  - Codified in regulation at **23 CFR 655.603**
- **"Notice of Proposed Amendments" (NPA) is the official notice of proposed changes**
  - **Dec. 14, 2020**

    Published in *Federal Register* (**federalregister.gov**)
  - **May 14, 2021**

    Rulemaking docket closed (**regulations.gov**)

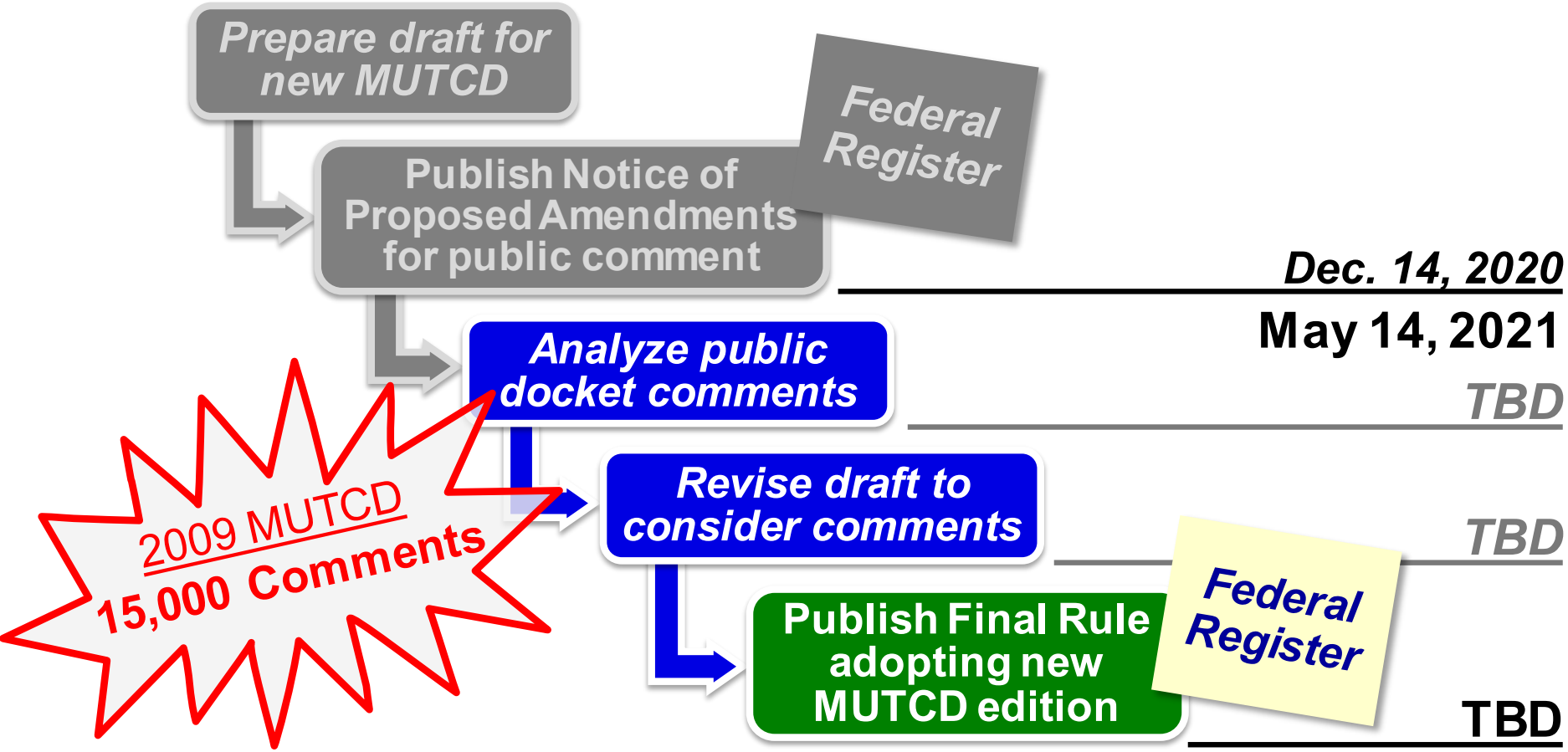
MUTCD – The Amendment Process

- **Revisions: The Rulemaking Process**



MUTCD – The Amendment Process

- **Revisions: The Rulemaking Process**



Proposed Changes

Proposed Lane and Edge Line Widths

- Based on Research on both Human Drivers and Safety, and Automated Driving Systems
- Propose **Normal-width** lines as
  - 6” wide for freeways
  - 6” wide where speed limit greater than 40 mph
  - 4” to 6” wide for all other roadways
- Propose **Wide lines** as
  - 8” wide where 4” to 5” normal lines are used
  - 10” wide where 6” normal lines are used

Proposed Part 5 – Autonomous Vehicles

- New Part—Provide agencies interested in AV systems with set of criteria
- **Not a requirement—**
  <u>Agencies decide</u> whether to fit roads for AVs
- Address current body of knowledge
- Expect systems to continue to evolve

There is <u>no</u> requirement proposed to fit roads and streets for Autonomous Vehicle systems.

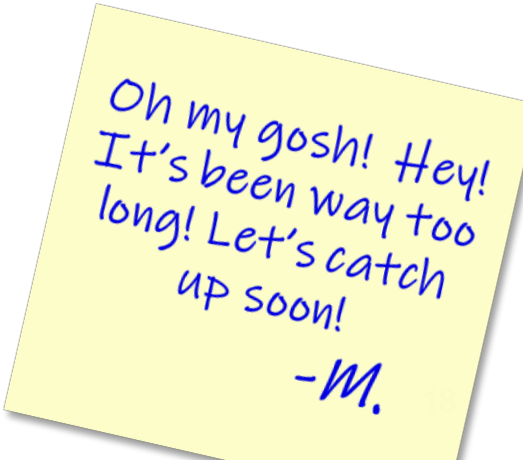
Proposed Part 5 – Autonomous Vehicles

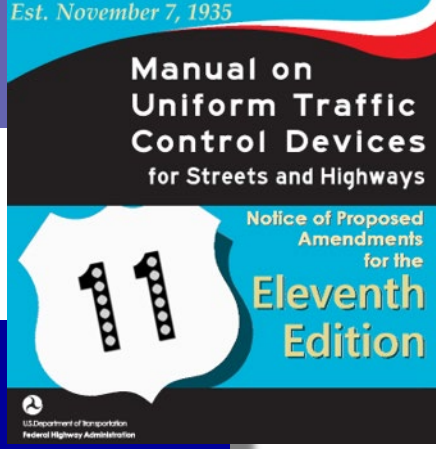
- Considerations proposed to accommodate AVs
- **No requirement to fit roads for AVs**
- Recommended factors include
  - Line widths
  - Sign orientation
  - Refresh/flicker rate for LED signs, signals
  - "Ghost" lines in Work Zones

The MUTCD addresses traffic control devices only. Vehicle systems are outside the scope of the MUTCD.

Looking Ahead

- **Update cycle**
  - **More frequent updating** through Revisions, every few years
  - Revisions are focused—not a new Edition
  - Still a rulemaking, but only a **fraction of the size**
  - Allows Interim Approvals, other advances to be **adopted much more quickly**
  - **Reduces volume and backlog** of changes when new edition issued





Thank you!!

How to reach us

https://mutcd.fhwa.dot.gov

(Web search "mutcd")

- e-Subscribe Service
- Official Rulings
- *Standard Highway Signs*
- FAQ
- MUTCD News Feed

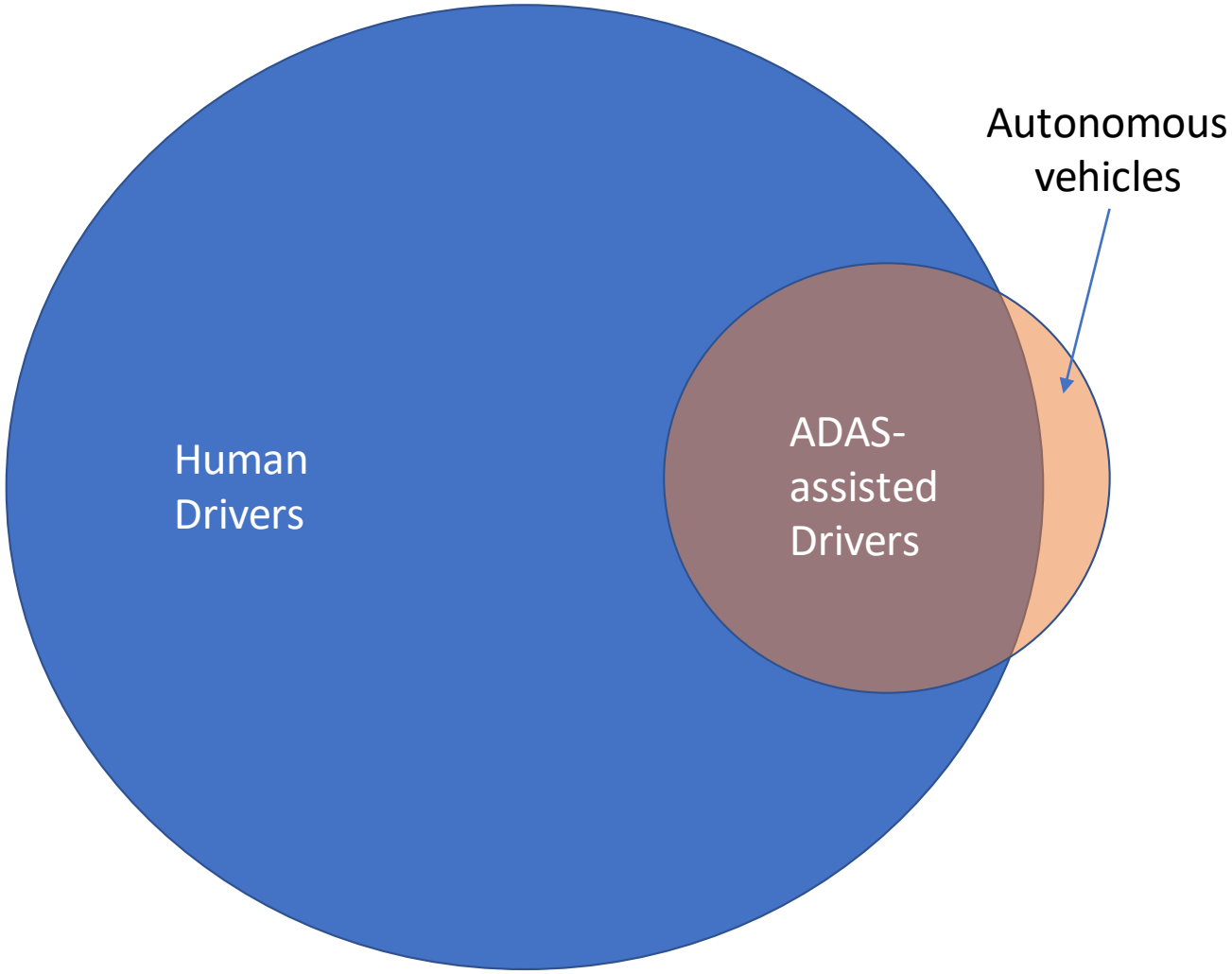
TRANSPORTATION RESEARCH BOARD

Changing the Manual to Support Deployment of Automated Vehicles

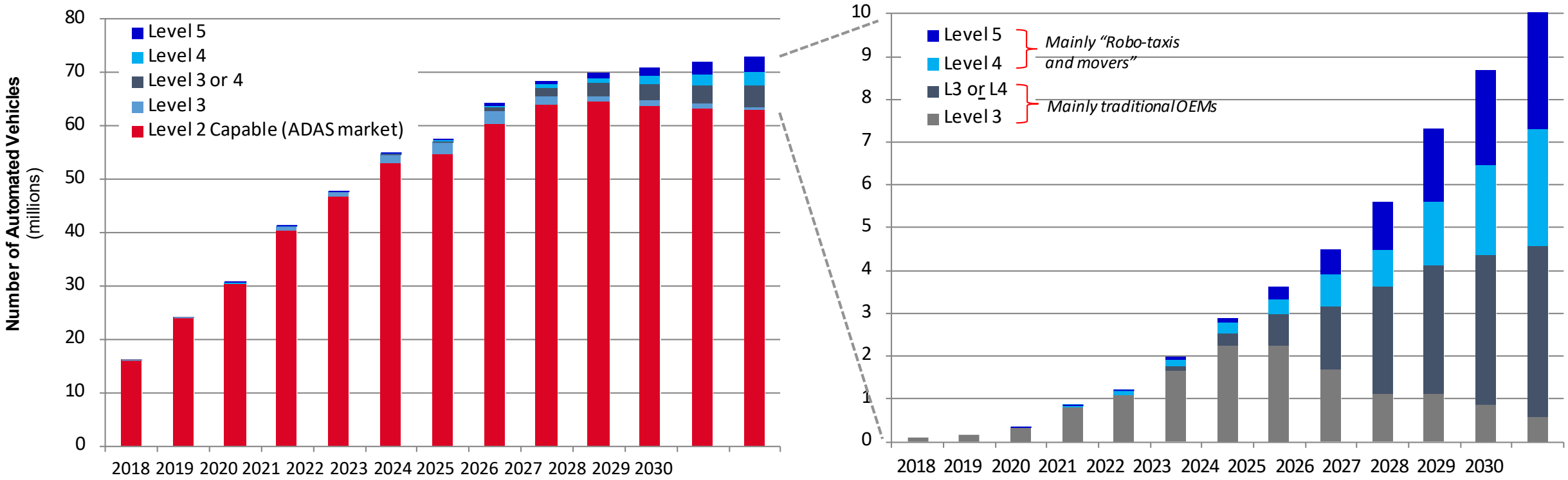
August 18 2021

Road User Categories

- For the foreseeable future, US roads will have a mixed driving fleet of human and automated drivers
- Human driving is vision-oriented; ADAS systems use vision heavily to integrate into a human driver-oriented world
- Automated vehicles can use other sensing technologies in addition, but these may not be usable by human drivers (e.g. radar, V2x)
- Technology improvements that benefit all three driver categories may provide the greatest benefits (return on investment)



Global ADAS / Automated Driving Market Growth

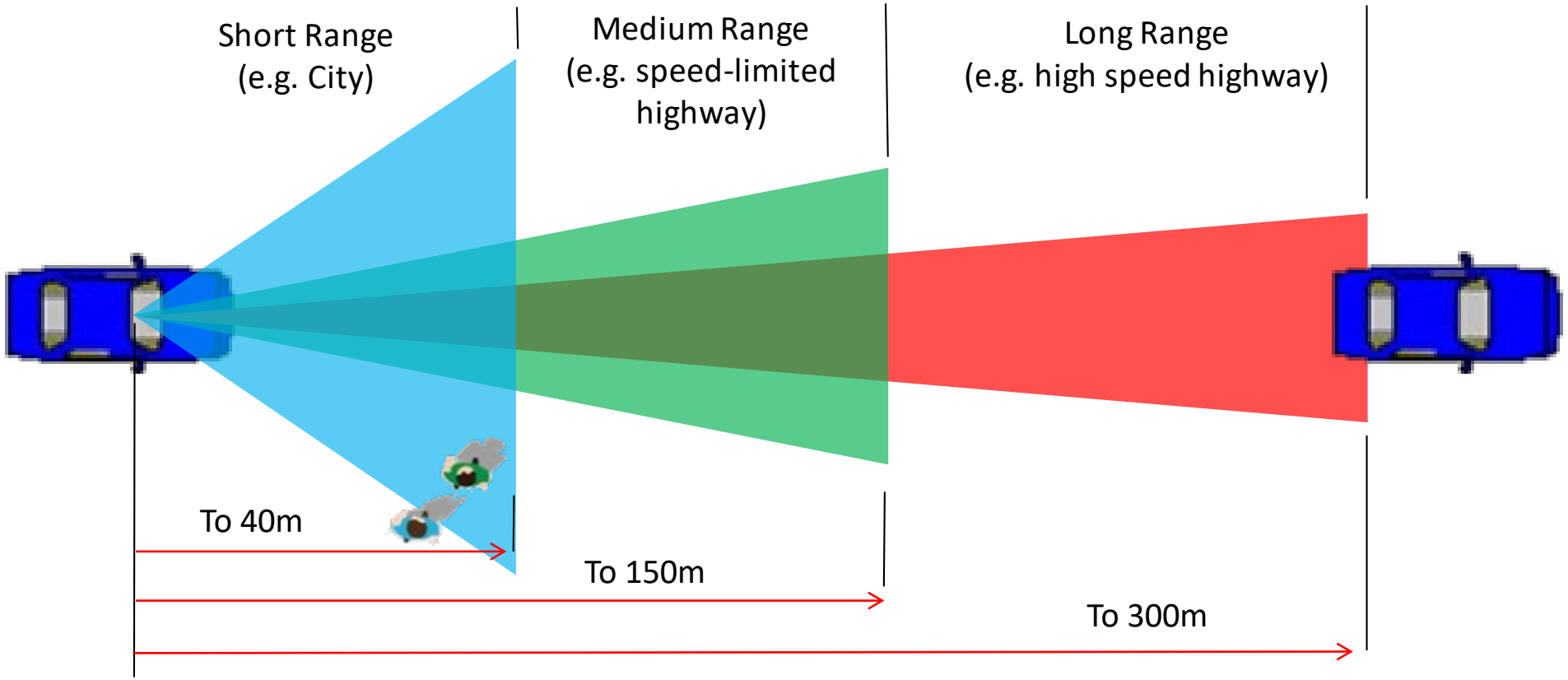


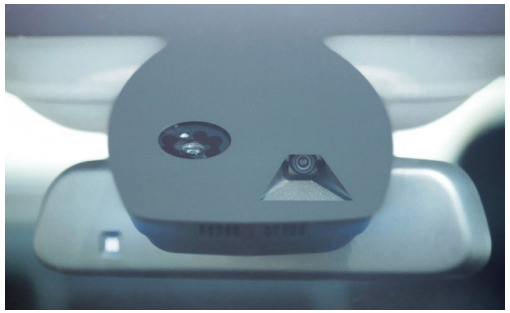
Data sources: 3rd party analyst data, IHS vehicle build forecast, ZF estimates

- Majority of AD market for the next 15 years will be ADAS-equipped, Level 2-capable vehicles due to regulation (e.g. European General Safety Regulation) and voluntary fitment of Automatic Emergency Braking (AEB) systems (e.g. USA) and Lane Keeping
  - By the end of 2022, 99% of new light vehicles sold in the USA will be equipped with camera and / or radar-based AEB systems
- Highly automated vehicle market expected to grow steadily to about 10% of the global vehicle market by 2030, split between dedicated AD vehicles and passenger vehicles with use-case specific automation (e.g. highway driving)
- **Traffic controls and infrastructure enhancements can benefit both segments of the ADAS / AD market**

Introduction to Camera

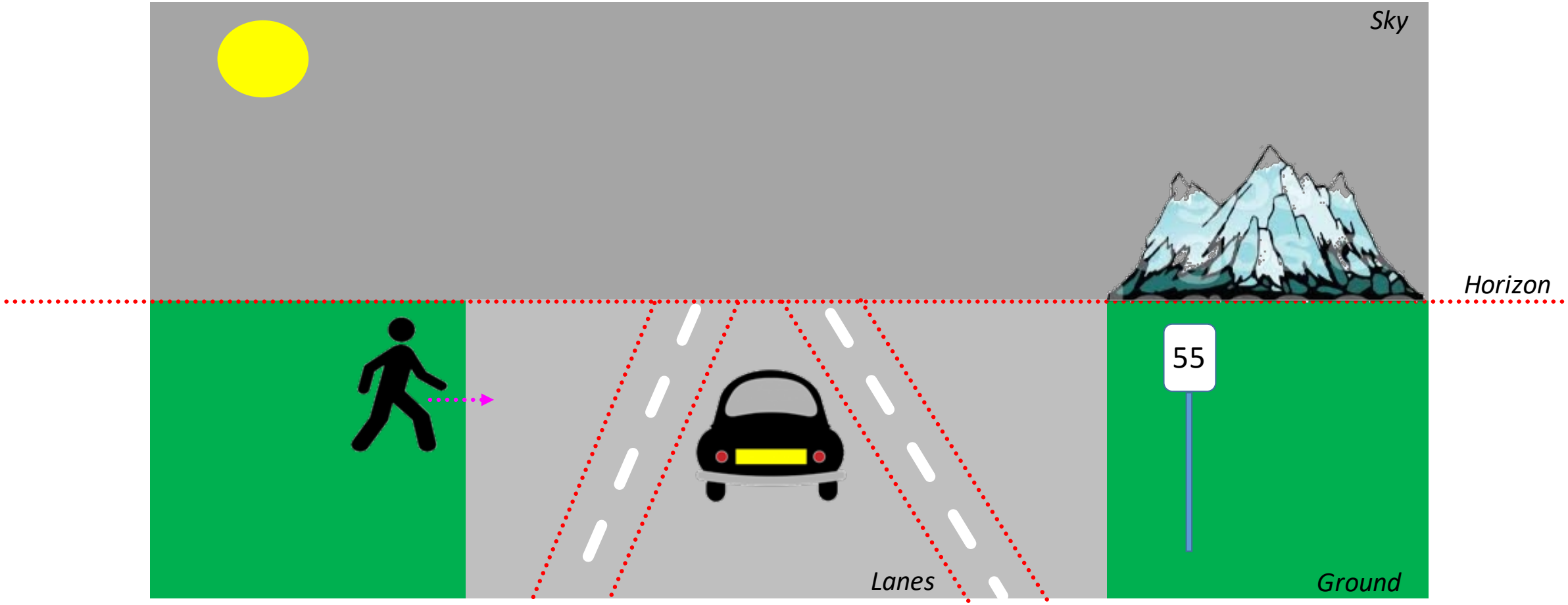
	Short Range	Medium Range	Long Range
Typical Field of View	100 - 180°	40 - 100°	20 - 40°





- Camera is a “passive” sensor – it only receives information about the environment (unlike radar with active signal transmission)
- Not as accurate at measuring distance and relative speed as a radar – can only estimate +/- 5-10%, but high resolution pictures (compared to other sensors) – very good at measuring angles and recognizing objects
- Typically mounted behind the rear view mirror, in an area of the windshied cleaned by the wipers

Camera Image Processing



- Camera takes a picture, and:
  - Identifies if light or dark; if dark, can turn on lights and control high-beams
  - Identifies horizon and looks for converging, contrasting lines (lane markings)
  - Looks for other important objects in the image – vehicles in the same and adjacent lanes, pedestrians, traffic signs etc
- Camera takes another picture, and compares the two to see what has changed – up to 35 times per second
- Delta information can be used to estimate movement and paths of other objects – e.g. pedestrian approaching roadway

Camera Performance Drivers

- Camera performance is determined by:
  - Lens design, quality and materials (glass or plastic)
  - Imager resolution (number of pixels, typically 1-2 megapixels today)
  - Imager sensitivity (especially at night time)
  - Frame rate (number of frames per second)

- Automotive grade cameras can provide a lot of detailed information about the environment, but are dependent on light levels and weather conditions (e.g. fog, snow, rain) for best performance and are relatively low resolution today (1-2MP) compared to consumer cameras
  - If the driver can't see road markings, a camera probably can't see either – cameras can see a little better than the human eye
  - If a driver can see road markings, a camera may not be able to see them (contrast)

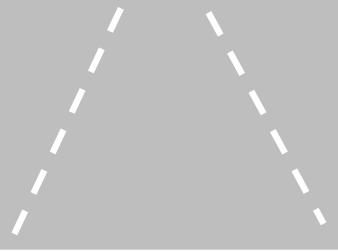
  Vision software requires an object to have a minimum number of pixels width for recognition (typically around 20)

Camera Drivers Continued

- Camera detection range is determined by lens field-of-view and imager resolution – the number of pixels per degree of field-of-view
  - A higher resolution imager enables a longer range with the same lens – x pixels width object can be detected further away
  - A wider field-of-view lens reduces range with the same imager – fewer pixels per degree

- **Object size and lane marker width directly impacts detection range – e.g. wider lane markings can be detected at longer ranges**

How Can Road Infrastructure Help ADAS-Equipped Vehicles?

Camera Generation	Target Type & Detection Range (Time) @ 50mph			
				
Gen 1 (2004-14)	~15’ (0.2s)	~70’ (0.9s)	Up to ~300’	~275’ (3.6s)
Gen 2 (2015-21)	~25’ (0.3s)	~110’ (1.5s)	Up to ~460’	~430’ (6s)
Gen 3 (2022+)	~30’ (0.4s)	~140’ (2.0s)	Up to ~490’	~575’ (8s)

- ADAS camera systems in the field already and in the near future are highly attentive, but have limited resolution and range vs. some human drivers
- **Road safety improvements** aimed at older drivers can also **benefit ADAS cameras**, **including those already in the field**:
  - 6” wide highway lane markings vs. 4” allow lanes to be detected and tracked significantly further ahead of the vehicle
  - Larger safety-critical road signs (e.g. 48” STOP sign vs. 36”)
  - Wider highway construction markers allow construction zones to be detected further ahead of the vehicle
- Standardization of traffic signs and signals, in terms of design and mounting location, can improve reliability of detection by reducing complexity of machine vision processing

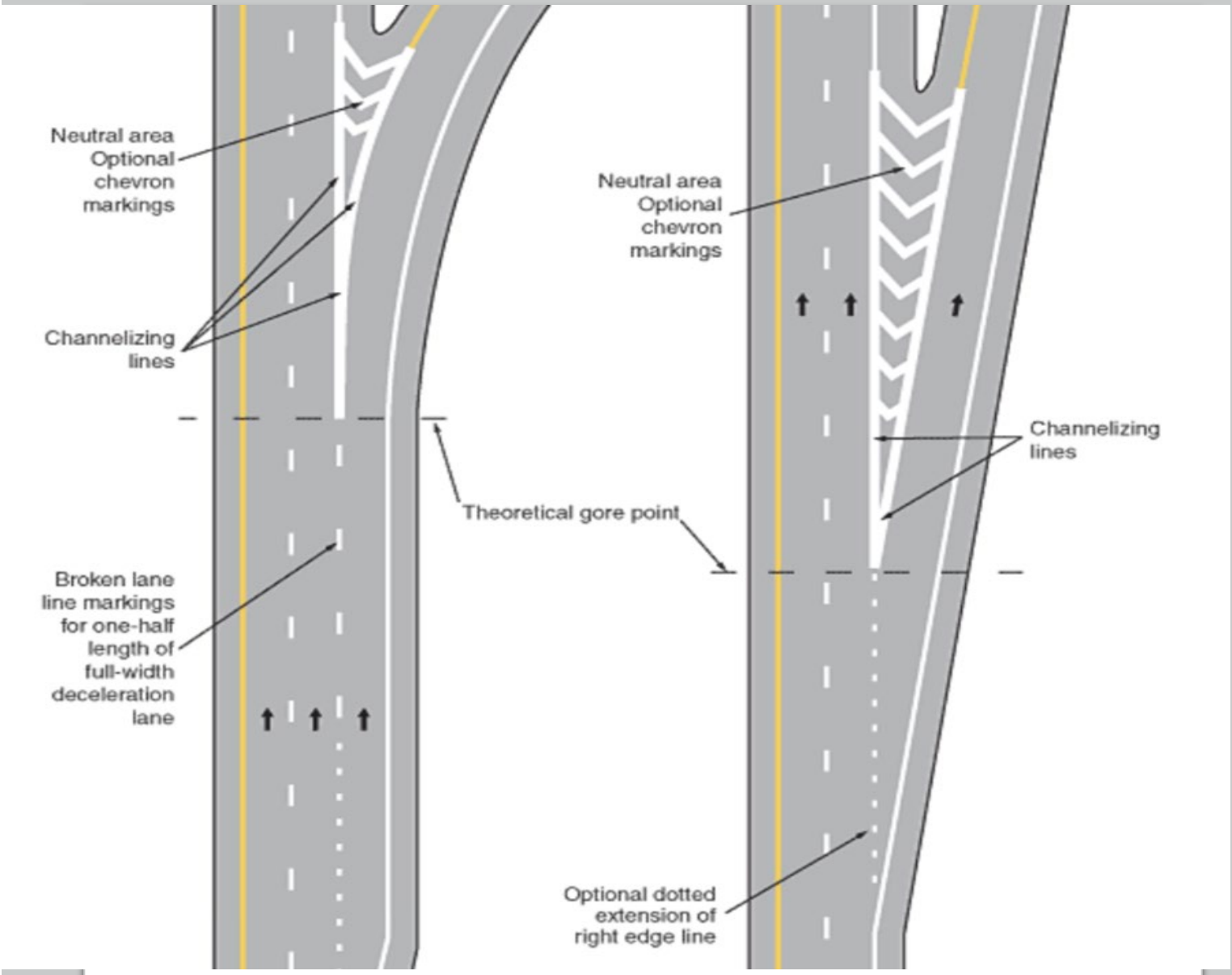
ASC/ATSSA MUTCD Leadership

- March 2018 ASC Booth at ITS Conference meets ATSSA representative
- August 2018 ASC presents at ATSSA mid year meeting
- January 2019 ASC presents at ATSSA annual meeting and forms joint working committee
- May 2019 ASC hosts ATSSA/SAE at Aptiv for committee meeting on pavement markings and MUTCD proposal
- January 2020 NCUTCD Committee meets to approve ASC/ATSSA proposed pavement markings
- December 2020 FHWA issues NPA on first update to MUTCD since 2009 with the proposed changes on pavement markings to aid ADAS/ADS vehicles
- Next steps : repeat the process for guardrails, signals & signs

MUTCD Changes to Assist ADAS/AV

- The illuminated portion of electronic-display signs / traffic signals using LEDs should have a standard refresh/flicker rate. The refresh rate of the LEDs should be greater than 200 Hz to be easier for the camera to detect.
- Normal-width longitudinal lines on freeways, expressways, and ramps of at least 6 inches wide (see Section 3A.04).
- Edge lines of at least 6 inches in width on roadways with posted speeds greater than 40 mph (see 28 Section 3B.09).

Lane extensions at interchanges made standard



MUTCD Changes to Assist ADAS/AV

- Temporary Traffic Control (Work Zones)

To better accommodate machine vision used to support the automation of vehicles, channelizing devices should be at least 8 inches wide with retroreflective material for reliable machine detection in all weather conditions. Markings entering the work zone and through lane shifts should be made with highly visible and continuous materials, not intermittent buttons and reflectors.

- Railroad Crossings

For passive and active grade crossings, placement of signs and markings should be consistent along a corridor to promote uniformity and to improve the ability of machine vision technology to recognize highway-rail grade crossings.

MUTCD Changes to Assist ADAS/AV

- ADAS Sensors are the building blocks for future AV's. More roads made readable expands the usage of ADAS/AV.
- Well paved roads with good maintenance standardized across all states is very important.
- Standardized large signs placed uniformly along roads are needed
- Black /white alternating lines on light colored pavement is needed for contrast in both wet and dry conditions. Not "Oreo" lines
- Construction Zone improvements are needed
- STANDARDIZATION / STANDARDIZATION/ STANDARDIZATION

What Does a Vehicle Need to See for Automated Driving?

Everything!

- For highly automated driving, more complex sensor systems are needed to fully understand the vehicle's environment

Automotive Safety Council Members

Adient Aisin Aptiv ARC Ascend Autoliv

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Yanfeng ZF

Thank You!

Changing the MUTCD to Support Deployment of Automated Vehicles

Ted Bailey, PE
Washington State DOT
Cooperative Automated Transportation Program Manager

TRB Webinar: August 18th, 2021

1-2:30 PM EST

Part 5 – Automated Vehicles

Proposed MUTCD content that needs more discussion

1. Should AV have a dedicated chapter?
2. Is the content sufficiently multimodal?
3. Are guidance statements helpful or should the content focus on the standards?
4. 5B.01 LED Refresh rates?
5. 5B.02 Pavement marking width, 6” Standard vs Other options / Funding?
6. 5B.04 Temporary Traffic Control markings, is this possible during all weather conditions?
7. 5B.06 Bicycle Facilities

Part 5 – Automated Vehicles

Proposed MUTCD content that is on the right track

1. Agencies should adopt traffic control device maintenance policies and or practices with **consideration to both the human vehicle operator and ADAS technology needs**

2. Establish maintenance policies that incorporate effective practices to **fix or replace traffic control devices that have reached their end of useful life** in a timely manner.

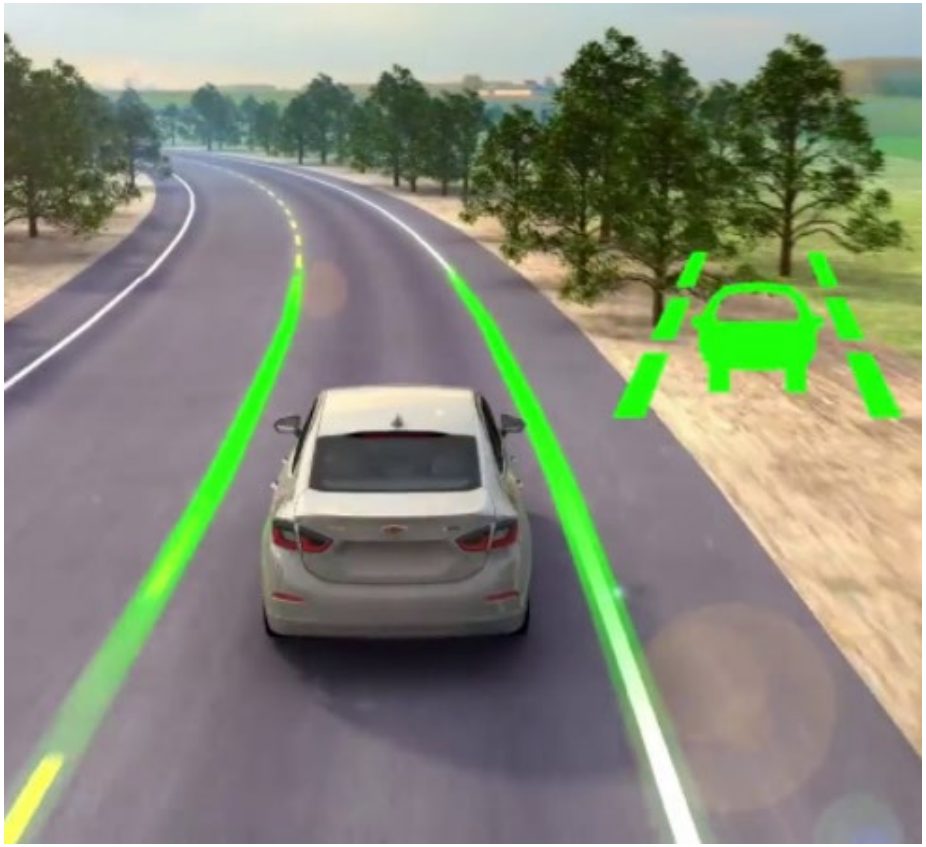
WSDOTs Approach

Pavement Markings:

Good for Humans and Machine Vision Today

Striping and marking investments are the least cost / highest return investments for keeping driven and automated vehicles safely on the road.

With aging drivers and automated systems, higher quality striping is now an operational need rather than a simple maintenance or preservation task.



Benefit / Cost 78:1

Pavement Markings:
Proposed MUTCD Changes

PART 3. MARKINGS

Section ~~3A.06~~3A.04 Functions, Widths, and Patterns of Longitudinal Pavement Markings

Standard:

The general functions of longitudinal lines shall be as follows:

A. A double line indicates maximum or special restrictions.

B. A solid line discourages or prohibits crossing (depending on the specific application).

C. A broken line indicates a permissive condition.~~, and~~

D. A dotted lane line provides ~~guidance or~~ warning of a downstream change in lane function.

E. A dotted line used as a lane line or edge line extension guides vehicles through an intersection, a taper area, or an interchange ramp area.

The widths and patterns of longitudinal lines shall be as follows:

A. Normal width line ~~4 to 6 inches wide.~~ 6 inches wide for freeways, expressways, and ramps; 6 inches for all other roadways with speed limits > 40 mph, 4 to 6 inches for all other roadways.

B. Wide line ~~at least twice the width of a normal line~~ at least 8 inches in width if 4 inch or 5 inch normal width lines are used and at least 10 inches in width if 6 inch normal width lines are used.

Notice of Proposed Amendments – Part 3 Page 337 of 781 December 2020

- Proposed additions to the MUTCD are shown in blue underline

Pavement Markings:

Proposed MUTCD Changes, Exit Ramp Example

Figure 3B-8. Examples of Dotted Line and Channelizing Line Applications for Exit Ramp Markings (Sheet 1 of 2)

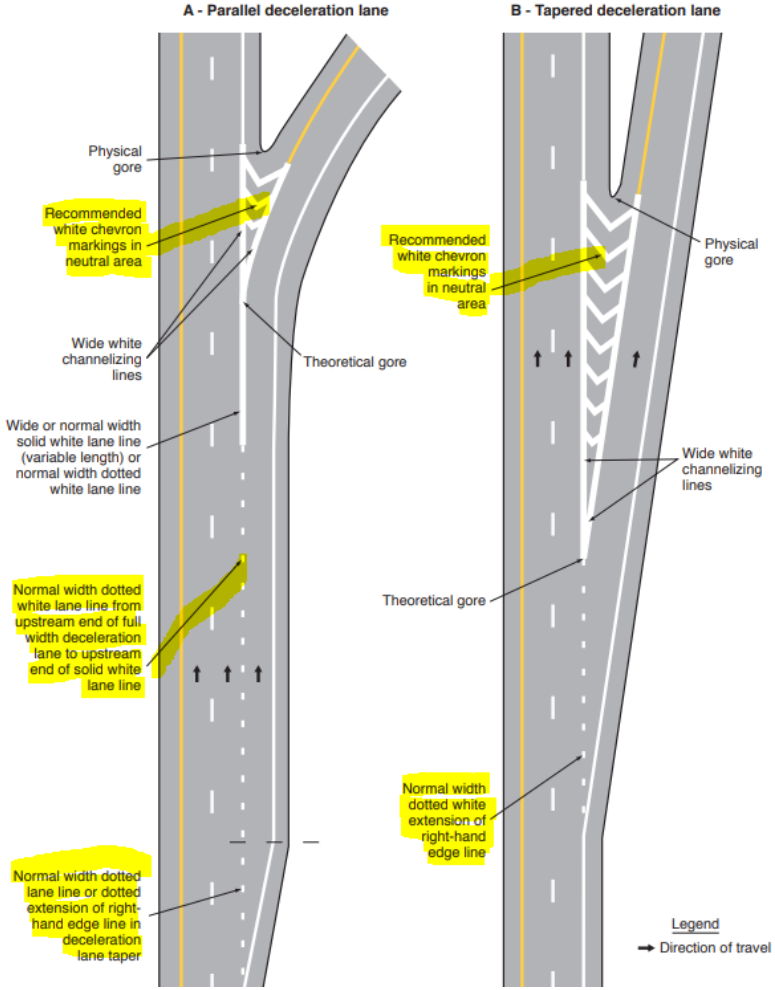
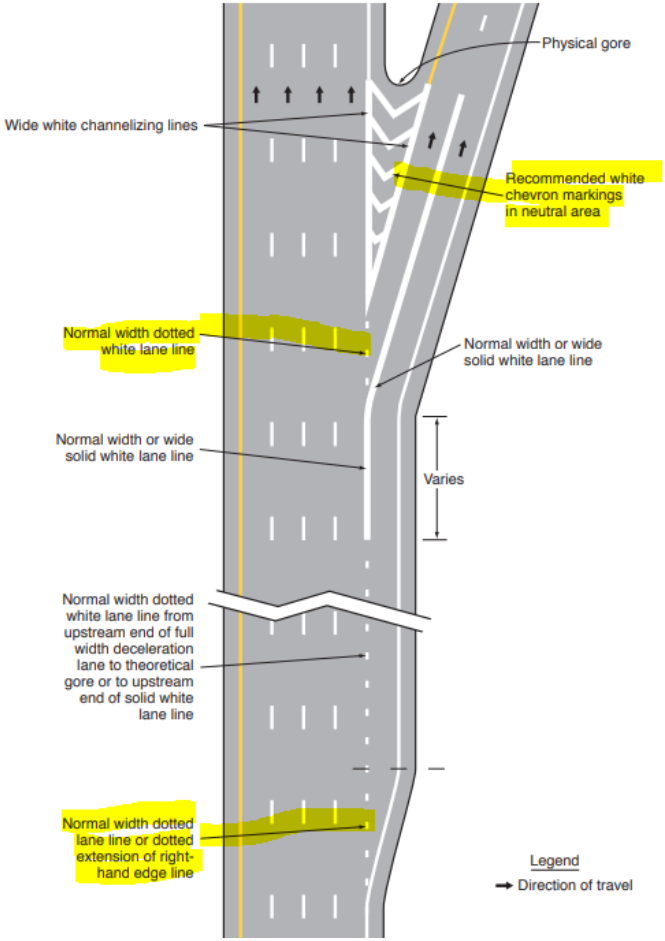


Figure 3B-8. Examples of Dotted Line and Channelizing Line Applications for Exit Ramp Markings (Sheet 2 of 2)

C – Parallel deceleration lane at a multi-lane exit ramp having an optional exit lane that also carries the through route



Future Pavement Markings:

Wet Locations

- 4 inch-wide High Build (thicker) paint improves wet weather bead adhesion while bead optics allow for wet night retro-reflectivity.
- 6 inch-wide markings at the standard 15mil thickness with the standard glass bead would **provide little to no-increase** in nighttime retro-reflectivity during wet conditions. *(WSDOT Opinion)*

- Wet performing package: Standard 4 inch-wide line, 17 to 22.5 mil high build paint, 8 lbs/gal wet weather bead mix

Future Pavement Markings:
Dry Locations

- Wider 6-inch lane and edge lines provide increased visibility and contrast over traditional 4-inch lines during day and dry night conditions.

- 6-inch line package: 15 mil paint, 7 lbs/gal standard 1.5 RI glass beads

Pavement Markings: WSDOT Approach

WSDOT Annual Long Line Striping Budget (Materials ONLY / Year)

- **Statewide Today: S**tandard 4 inch wide, 15 mil paint, 7 lbs / gal, standard bead $5 Million / Year

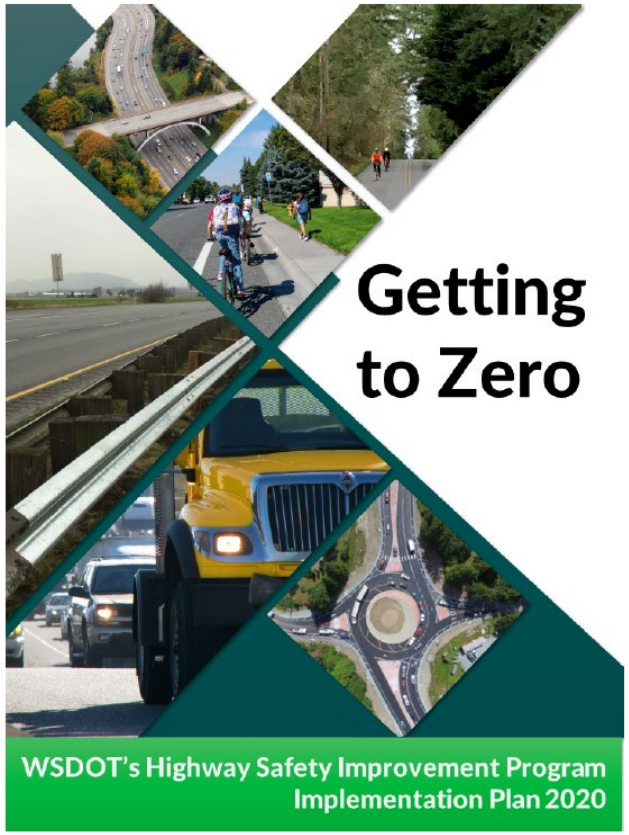
  (Note: Cost to cover 60-80% of the system on an annual basis, MAP Level B, Painting 100% of the system with the goal of provided presence and retro 247/365 would require additional investment)
- **Proposed Approach:**
  - **Eastern Washington (Dryer, Hot/Cold Climate)**
    - Wider 6-inch-wide marking, 15 mil paint, 7 lbs/gal standard bead $4.3 Million / Year
  - **Western Washington (Wet, Temperate Climate)**
    - Standard 4-inch-wide, 17-22.5 mil high build paint, 8 lbs/gal all weather bead mix *(approx. 70% standard bead, 30% composite bead)*

      $4.2Million / Year
- **Material $ delta between Today and Preparing for AV?** $3.5 Million / Year

Pavement Markings:

Crash Reduction Potential

- **Lane Departure Crashes are associated with nearly 50% of all fatalities in WA state (2003-2017)**



High Visibility Edge Lines

Edge lines are the solid white longitudinal markings at the outside edge of roadways. High visibility edge lines increase the driver's ability to see the markings, helping reduce lane departure crashes. The Edge Line Visibility Pilot will potentially reduce run-off-the-road crashes by installing high visibility edge lines on rural highways and freeways in Western Washington.

Introduction

The Edge Line Visibility pilot attempts to reduce lane departure crashes, which is one of the Target Zero focus areas. WSDOT will establish high visibility edge lines in three Western Washington regions. The pilot will focus on rural routes and freeways on the west side of Washington state. Studies have shown that increasing edge line visibility by having wider or thicker lines with high visibility beads can reduce run-off-the-road crashes by up to 35%. This pilot will install high build, or thicker than average, 4-inch wide edge lines on target roadways.

Methodology

Crash Modification Factors (CMF) are used to compute the expected number of crashes after implementing a strategy intended to reduce crash frequency or severity on a road or intersection CMF No. 4792 in the Federal Highway Administration's clearinghouse for crash modification factors increases the edge lines from 4 inches to 6 inches and has a value of 0.78, or a 22% reduction in crashes. The CMF has a rating of 4/5 and used a before/after study with empirical Bayes methodology, a type of statistical estimation that addresses randomness and increases precision compared to using a crash history.

WSDOT will examine the three Western Washington regions in this pilot, with a focus on rural highways and freeways. Urban highways were excluded as many have curbing and no edge line, and potentially have lower travel speeds. All injury lane departure crashes were included in the screening and a 20% crash reduction is assumed.

Key Takeaway

- Assuming a 20% reduction in crashes following edge line visibility treatments, the expected benefit/cost ratio is 78:1.

Using the proposed high build 4-inch edge lines will provide benefits for all conditions, according to the research cited in the introduction. Other benefits may include improved readability by smart vehicle technology and road stripes maintaining visibility over longer periods of time. Based on the available research and CMFs cited above, a 20% reduction in lane departure crashes is a reasonable estimate.

WSDOT

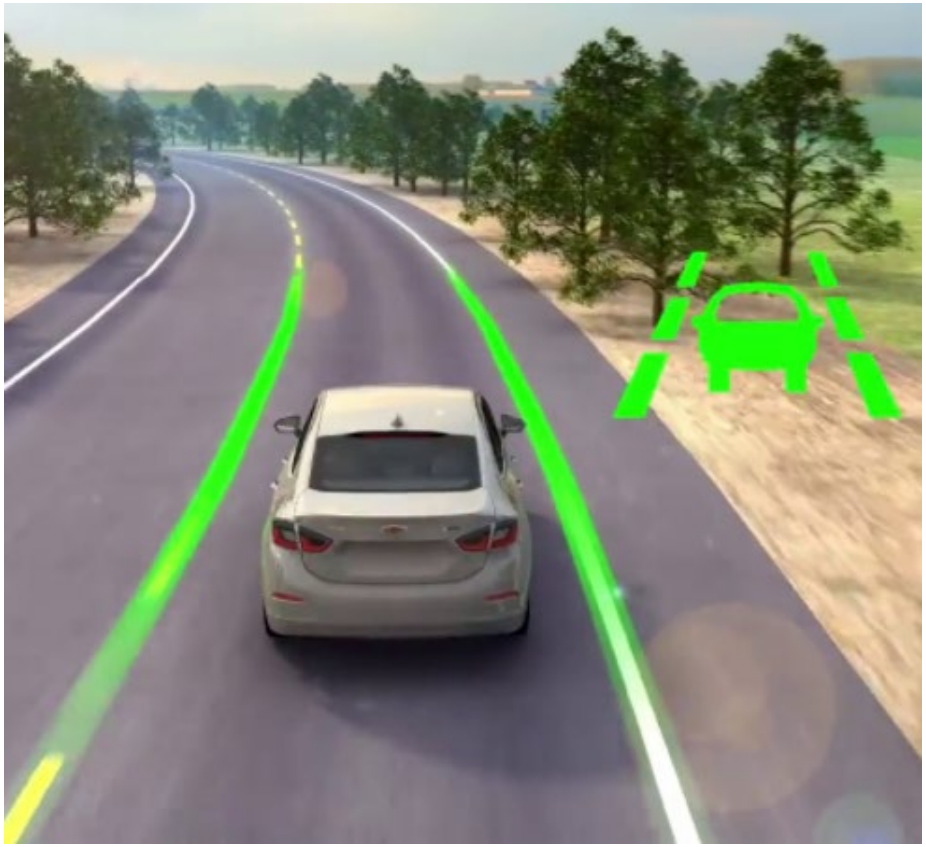
2020 Washington State Safety Implementation Plan – 53

Pavement Markings:

Good for Humans and Machine Vision Today

Striping and marking investments are the least cost / highest return investments for keeping driven and automated vehicles safely on the road.

With aging drivers and automated systems, higher quality striping is now an operational need rather than a simple maintenance or preservation task.



Benefit / Cost 78:1

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- *September 27*: **TRB Webinar: Innovations in Using Vehicle Probe, Connected Vehicles, and Cellular Data**

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