National Committee on Uniform Traffic Control Devices

Connected-Automated Vehicle (CAV) Task Force

TCD suggestions for Automated Driving Systems (ADS)

Feedback from Automotive OEMs

February 25, 2019

Abstract

After the January 2019 NCUTCD meeting where the FHWA confirmed that they are working on a new MUTCD, the NCUTCD CAV Task Force engaged the Auto Alliance to obtain information that could be used to generate discussion and direction concerning the need of traffic control devices to support the deployment of automated driving systems (ADS). The strategy employed was to share the news of an upcoming revision of the MUTCD along with the strawman proposal that was developed by the Markings Technical committee's ADS-RFI Task Force. The strawman proposal includes preliminary suggestions that address pavement marking uniformity issues thought to be helpful to both machine vision systems that provide partial-to-full automation as well as human led vehicles. The specific request was broader than just pavement markings. The anonymized results of the effort are described in this document.

The Auto Alliance (Alliance of Automobile Manufacturers) is the leading advocacy group for the auto industry, represents 70% of all car and light truck sales in the United States, including the BMW Group, Fiat Chrysler Automobiles, Ford Motor Company, General Motors Company, Jaguar Land Rover, Mazda, Mercedes-Benz USA, Mitsubishi Motors, Porsche, Toyota, Volkswagen Group of America and Volvo Car USA.

Disclaimers

- *The comments included in this document are 'raw' and taken from the feedback. In some cases, there is room for interpretation and follow up. The comments have only been anonymized and categorized for ease of use.*

- *This is a working draft of suggested TCD practices made by the auto industry to support the deployment of ADS. This material has been developed by the CAV Task Force of the NCUTCD to provide material that can be used to focus discussions and direction within the NCUTCD technical committees. This document does not represent a formal NCUTCD proposal for MUTCD changes. Furthermore, the material presented herein do not represent NCUTCD proposed recommendations for changes to the MUTCD, nor does the material represent an official proposed revision of the MUTCD.*

Initial Request

Addressing Cooperative Automated Transportation (CAT)
in the Manual on Uniform Control Devices (MUTCD)

The FHWA has announced efforts to update the MUTCD. The National Committee on Uniform Traffic Control Devices (NCUTCD) is working to identify traffic control device (TCD)-related information that can be used to update the MUTCD tha support CAT while meeting the needs of current road users.

Background:

Traditional OEMs and new entries in the vehicle industry are introducing new technology in vehicles today. With this in mind, FHWA is preparing to support these new technologies today and in the future through the MUTCD. These initial technologies (lane departure warning, lane keep assist, and sign recognition for example) are the first steps toward full deployment of CAT.

Interoperability is a critical piece of the successful deployment of CAT. This will ensure that vehicles will be able to operate with the same level of safety, comfort and convenience in all areas. To support interoperability, TCD uniformity will be an important component of CAT. Widespread compliance with the MUTCD will improve uniformity and help ensure the successful introduction of a variety of levels of automation in a mixed fleet for the foreseeable future. The mixed fleet will continue to have manually operated vehicles driven by humans. Widespread uniformity of the MUTCD will also benefit human drivers as well as low, mid and high levels of CAT.

There continues to be a great deal of research being conducted on many aspects of CAT. Sensor technology, processing power and development of vehicle control continue to improve. Therefore, the following recommendations are the first steps in addressing CAT in the MUTCD. Future updates to the MUTCD can address new technology and findings from TCD-related research regarding CAT.

Recommendations:

As a foundation or initial step to support the deployment of vehicles with known aspects of CAT today and higher levels of CAT in the future, the NCUTCD CAV Task Force is focused on an initial effort aimed at increasing the uniformity of specific TCD practices. The following aspects of pavement markings are addressed in the current MUTCD but allow flexibility. To increase National uniformity, the NCUTCD CAV Task Force is considering developing MUTCD recommendations focused on the following areas.

- Pavement marking width - developing uniform width of longitudinal markings
- Skip line / gap dimensions - establishing uniform dimensions for skip line length and gap spacing
- Dotted edge line extensions - use of dotted edge line extensions along ramps
- Hatched markings inside gore areas - use of hatching (Chevron markings) inside gores
- Contrast markings used on concrete roadways

Request:

Your feedback is requested on the current focus areas, as well as other high priority areas that the NCUCTCD CAV Task Force should be evaluating. Specifically, from your perspective, are the bulleted items expected to be beneficial for machine vision systems (please describe)? Are there other pavement marking uniformity issues that should be considered? Beyond pavement markings, are there other areas within the TCD space that would benefit machine vision systems with increased uniformity? Finally, from your perspective, please suggest/describe other TCD-related areas that should be considered to support the development of CAT in the MUTCD (i.e., beyond uniform applications of TCDs).

Please respond to the Task Force chair: Paul Carlson, pcarlson@roadinfrastructureinc.com The MUTCD is available on-line at: https://mutcd.fhwa.dot.gov

1. Direct Input on Bulleted Items from Initial Request

1.1. Pavement marking width – developing uniform width of longitudinal markings
- Yes, this would be particularly beneficial for machine vision.
- Not sure about a specific dimension but thin markings are problematic and should be avoided.

1.2. Skip line / gap dimensions – establishing uniform dimensions for skip line length and gap spacing
- Not an issue for us
- Yes, this is particularly beneficial for machine vision.

1.3. Dotted edge line extensions – use of dotted edge line extensions along ramps
- These would be very useful and we would love to see them implemented more consistently
- Yes, this is particularly beneficial for machine vision. It would help for roundabouts too.
- Also include dashed lines across entrances of turn lanes and lane splits
- Require dashed intersection turn lines for irregular geometries or long intersections, and for dual turn lanes

1.4. Hatched markings inside gore areas – use of hatching (Chevron markings) inside gores
- We prefer to not have chevron markings inside of gore areas. In some circumstances these chevron patterns could be erroneously detected as lane markings.
- Standardizing the hatched marks inside gore areas (right now, adding the hatched markings is optional so you end up with a mixture of some gore areas hatched and others not)

1.5. Contrast markings on concrete roadways
- On concrete roads mandate adding both the white and black colors to increase contrast


35W
12
35W
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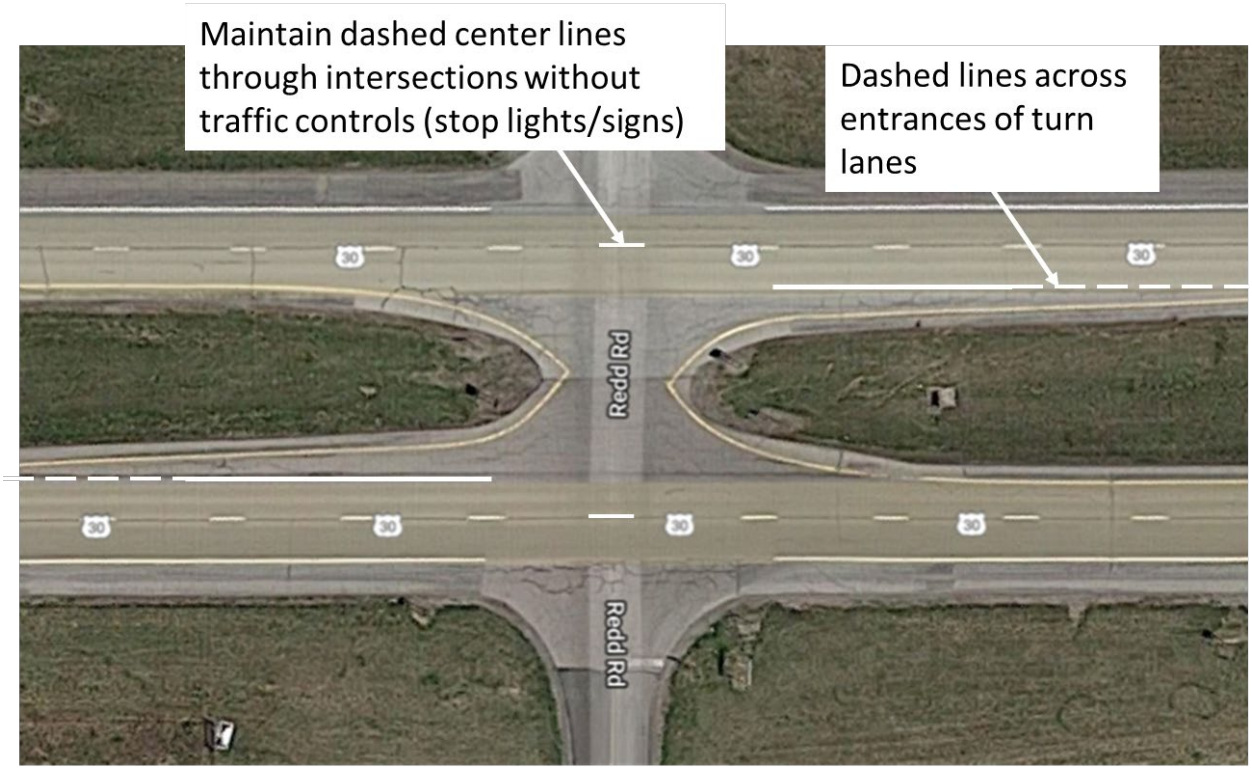
35W
Add dashed lane lines across entrance ramp and exit ramp openings in all states. Some states do this today.


Maintain dashed center lines through intersections without traffic controls (stop lights/signs)
Dashed lines across entrances of turn lanes
Redd Rd
Redd Rd


Dashed lane line across lane add entrances
Walter P Reuther Fwy
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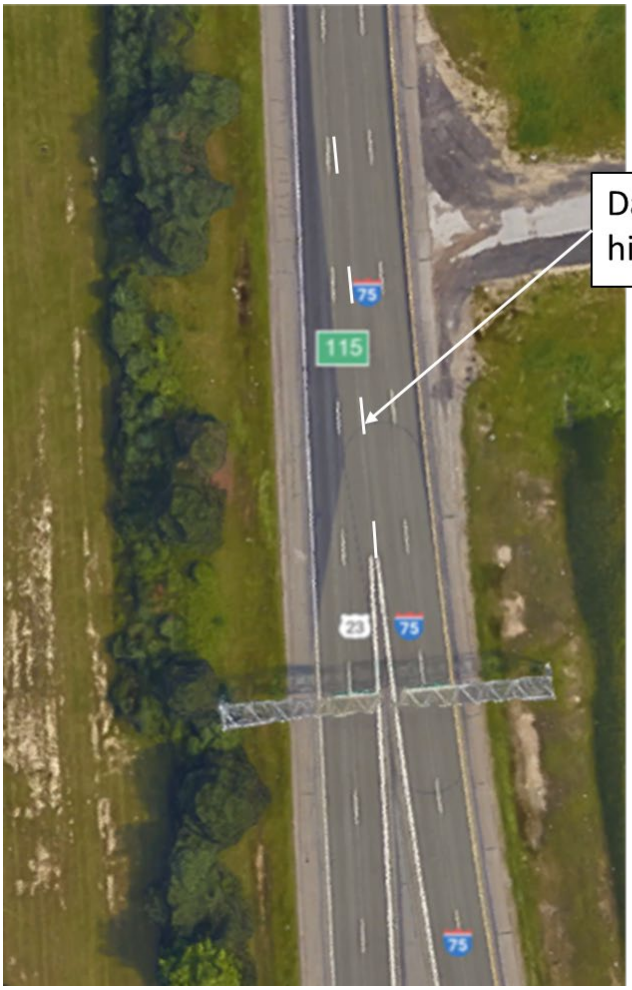

Dashed line across lane split following higher ADT roadway.
75
115
23
75
75


On concrete roads mandate adding both the white and black colors to increase contrast
Baltimore Beltway
Baltimore Beltw

2. MUTCD Part 2 and 7 – Traffic Signs (including School Areas)

2.1. General

- Standardize all traffic signs throughout the entire country.
- Use mainly pictograms, limit use of text. In situations where text is necessary: The content of the text shall be standardized
- Do not allow unique state specific traffic signs.
- All road signage should have good retroreflective background.

2.2. Electronic Signs

Electronic Signs need to be standardized with reference to:

- Color – White background color with black text. This background should be retroreflective or illuminated.
- Shape – All electronic signs should be rectangular in shape and have the same dimensions (standard length and width).
- The entire sign should be illuminated.
- The illuminated portion 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. If the refresh rate is known and is standard for all electronic signs, then they will be much easier to correctly detect.
- Position – The height of all electronic signs should be standardized and not exceed 17 feet in height as measured from the ground to the bottom of the sign.

2.3. Speed Limit Signs

- The speed limit sign should be clearly associated to its specific lane/road. For example in the case of parallel roads with different speed limits.

2.4. School signs

School speed limit signs need to be standardized with reference to:

- Design – All school speed limit should have a yellow “SCHOOL” sign affixed directly above a speed limit sign.
- If there are conditional School signs (for example, “When Children Are Present), the content of the text shall be standardized.
- Shape – All school speed limit signs should be rectangular in shape and have the same dimensions (standard length and width).
- Position – The height of all school speed limit signs should be standardized and not exceed 17 feet in height as measured from the ground to the bottom of the sign.
- Illumination – If the speed limit value of a school sign is to be illuminated, it 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. If the refresh rate is known and is standard for all electronic signs, then they will be much easier to correctly detect.

2.5. End school zone

End school zone signs need to be standardized with reference to:

- Design – All end school zone signs should display the text “END SCHOOL ZONE” with no other additional text.
- Shape – All school speed limit signs should be rectangular in shape and have the same dimensions (standard length and width).
- Position – The height of all end school zone signs should be standardized and not exceed 17 feet in height as measured from the ground to the bottom of the sign.

2.6. Future signs

- We like the 3M concept of placing infrared-readable bar code type markings on signs for reliable machine-reading, but recognize this may take longer to implement.

2.7. Other sign topics

- Road signs for “No Turn on Red” and Speed limits (e.g., multiple speed limits on one sign for night/day/truck/minimum speed).
- Lighted signs for time-of-day-dependent lane directionality (e.g., a center lane that changes travel directions based on morning/evening commute. Some cities use green/red arrows, some use green/red circles in over-lane lighted signs)
- Many states have additional road signs which are not included in the MUTCD. For example, we have noticed that the State of California implements road signs for speed zone ahead (R2-4(CA)) or ending of a certain speed limit (R3 (CA)) which are not covered by the MUTCD. These road signs, as well as many other unique road signs in various States, should also be included in the consideration by the committee for a development of uniformity recommendation.
- For any R1-5 / R1-6 Yield Here to Pedestrian signage, ensure there is a stop line or yield demarcation accompanied with it
- Requirements for reporting temporary or moved traffic control signs (e..g, stop sign, temp traffic signal) ; or a new sign or message easily perceived by AVs to recognize such

3. MUTCD Part 3 – Pavement Markings

3.1. Painted lane-boundaries with good contrast

Perception of lane markings depends on high level of contrast difference between the lane marking and the road surface. Lane markings painted on a bright road surface such as concrete shall be enhanced by additional contrasting colored markings such as black markings left and right of the main lane mark

Yellow lane markings marking the left edge of the drivable road shall be enhanced as well by supporting the bright yellow color with black markings left and right to the main marking.

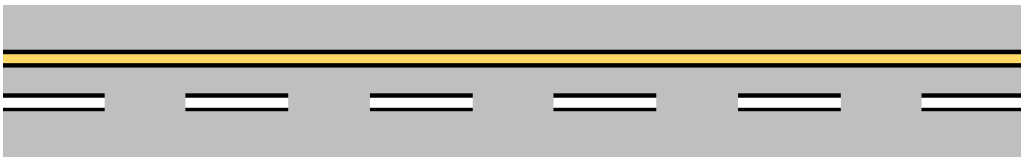


Figure 1: lane markings supported by additional markings of a different color

3.2. Reflectivity

Omni-directional reflectivity of lane lines to ensure directional sun doesn't wash out lines

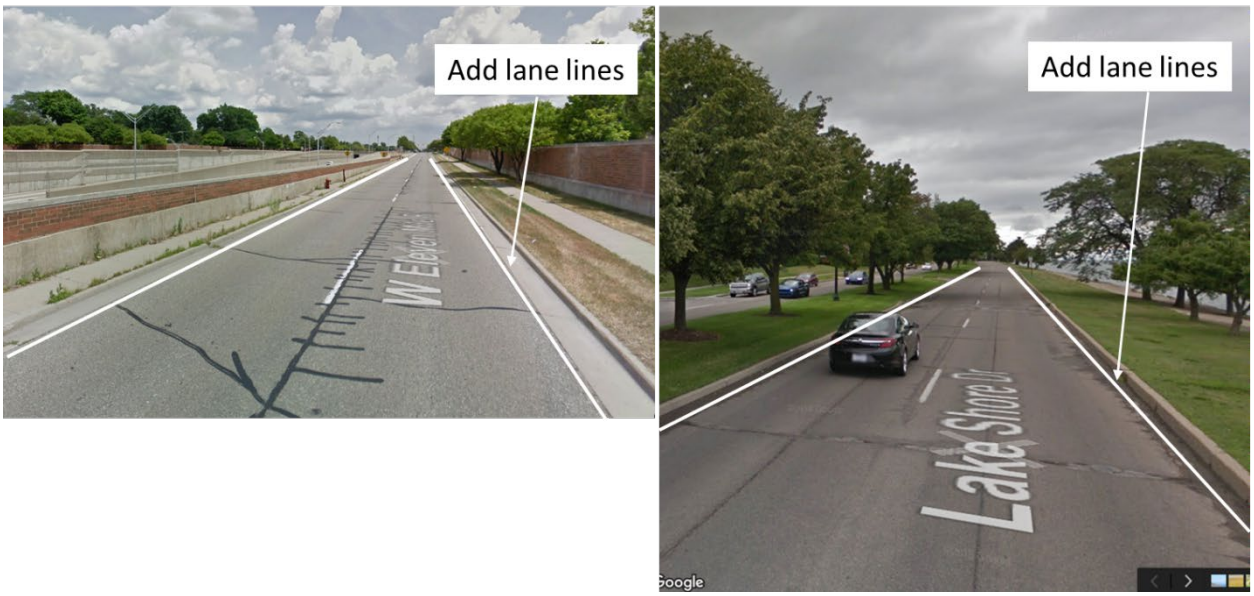
Mandatory restriping at some % of fade

It would be helpful to have highly reflective pavement markings for driving at night and in the rain (e.g., new markings in CA).

3.3. Edge Lines versus Curbs

Many roads use curb as an indicator of the right hand side of the lane. Curbs and other features have lower contrast than a white lane line. If a center line is present, always include an edge line.

Add lane lines for outside of lane indication when center lane line is present in addition to curb for increase contrast.



3.4. Non-dedicated exit lanes

Non-dedicated exit lanes leave areas with uncertainty where there is no sufficient guidance available. These areas shall be avoided by adding specific dashed lines along an exit scenario to drag traffic towards the main suggested path.

Figure 2: non dedicated scenarios added with dashed lane markings for additional guidance

3.5. Emergency areas/shoulders

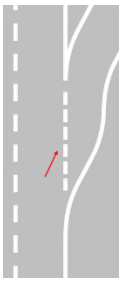
All freeways shall be equipped with emergency areas/shoulders on the side of the lanes. Even dedicated lanes (Special lanes like HOV) which are separated from the main lanes of the freeway should have access to emergency areas.

3.6. Botts dots

Botts dots shall be supported by a painted line below for better visibility by computer vision. The Botts dot itself should also be colored in a way that enhances its visibility in all weather or lighting scenarios.

- Shall be avoided in general
- If required Only together with lane markings/dashed lane
- Lane markings which provide acoustic feedback are generally preferred

3.7. Short dashed lane markings indicating exit only lanes



Short dashed lane markings shall be standardized in terms of

- Marking length (> 3ft)
- Marking width (> 10in)
- Distance between individual markings (> 5ft)

Between the individual marks of a high frequency lane shall be no other markings and/or other obstacles.

3.8. HOV/Express lanes

Dedicated separated lanes such as carpool or express lanes shall be separated from the main flow of traffic in a standardized and uniform way including:

- Separation to the main flow of traffic by a special type of lane markings (for example 2 or 3 solid white lane markings)
- Yellow lane markings for left road edge of separated lane
- Uniform entrance and exit scenarios including dashed lane markings

3.9. Hatched areas

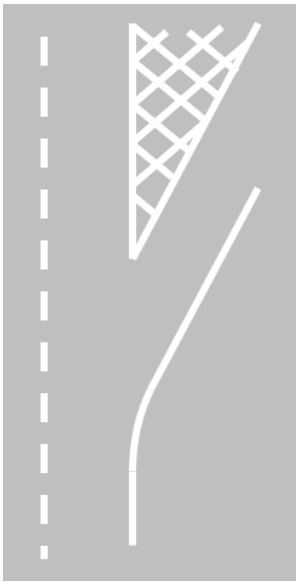


Figure 3: Hatched area after an exit scenario

In an exit scenario an open free space is created after the two separating lanes diverge from each other. This free space shall be marked as a non-drivable area of some sort. It is suggested to mark these areas by crossing lines in sort of a grid or hatch pattern. (See left)

Other non-drivable areas such as gore exit areas or areas in front of poles or barriers caused by the free space created by an exit may be specially marked as well.

3.10. Other Pavement Marking Items

- Car pool lane boundaries need to be more uniformly marked, including non-traversable areas and traversable (enter/exit) boundaries.
- Bike lane demarcations need to be more uniform
- Multi-line spacing for special use lanes (i.e., double yellow, car pool); it may be covered already in MUTCD but we have seen some non-conformity.
- Contrast markings (i.e., black/white lines used on concrete surfaces). Some States use longitudinal black/white, while others use lateral black/white/black. Pick one.
- Robust paint markings on the road that would help CAT (without an onboard map)
- Large freespace areas, such as large intersections and toll areas, need to be marked better.
- Lane endings and lane splits on highways. Paint more arrows on the particular lane that ends or splits to indicate which way the vehicle should go to stay on the main highway.
- Speed bump notifications (i.e., color of paint on the speed bump, chevrons leading to the speed bump).

4. MUTCD Part 4 – Traffic Signals

- More uniformity in traffic signals (incl. more uniform placement) would be helpful. Particularly problematical are horizontal traffic signals.
- Traffic light illumination requirements (including requirements for vision - seeing variable speed limits (and other types of ITS interactions, like V2I)
- Traffic lights should be standardized for the entire country including: Position, location, color, shape, refresh rate (greater than 200 Hz).
- The shape of traffic lights should be in the shape of light strips, either vertical or horizontal. There should not be block-shaped, T-shaped, or L-shaped traffic lights.
- The traffic lights should have a clear, unambiguous association with the specific lanes.
- Retroreflectivity guidance (e.g., is too much on certain signal backplates bad for AVs?)
- Have strict flickering cycle, color, intensity range; Don't have programable visibility using optical device (mechanical is ok); Light for different vehicle are not too close to each other to avoid confusion (no bike/muni light touching car light); They are positioned on polls in a way that facilitate lane light associations; Any intersection type change (stop to light) or light change is advertise in advance; Timecards have to be in electronic forms; On high speed road/ highway bulbs of different shape should not be showing on same lights.
- Frequency of LED bulbs in traffic signals. Is it standard?

5. MUTCD Part 6 – Temporary Traffic Control

- All construction sites should have traffic signs that warns the driver of an upcoming construction zone (e.g., Construction Site in ½ Miles).
- The end of a construction zone should be indicated by a clear standardized sign.
- Construction sites/road work should be clearly marked with e.g. orange temporarily lines that remain at their place on the road for a long time if there is a situation where the construction project has caused an absence of clear and visible lane markings for an extended period of time. These markings also shall be visible in rain or when run over to allow for good lane-keeping guidance.
- If the lanes become narrow, that has to be displayed in advance.
- Beacons/cones/barrels on construction sites should be equipped with good reflective materials/stickers and with a sufficient size for a good detection rate by computer vision even in rain and at night.
- Standardize the shape and size of the above beacons/cones/barrels.
- The wide variety of construction zone signs is problematical for ADS-operated vehicles (low contrast, variable text). They are especially difficult to "read" in low ambient lighting conditions or rain. Moving to pictorial signs with higher contrast would be helpful.
- Uniformity in the setup and signage of construction zones would also be very helpful for ADS-operated vehicles.
- Construction zone cone spacing (max spacing req)

6. Other Areas

6.1. Pylons

- Thin vertical poles are challenging to be detected in some situations by computer vision. For these reasons poles shall only be used in combination with proper lane marking for traffic guidance.
- Poles shall always be equipped with high reflective material in order to be better seen.

6.2. Barriers

- Concrete walls such as dividers should be marked with highly reflective markers, especially in the beginning section to enhance the visibility.
- The barrier and road separation should be clearly differentiated (good contrast between the barrier and road).
- Steel-rope-barriers are less visible than steel-beam-barriers by computer vision. Steel-beam-barriers or concrete walls with clear reflective markings are preferred.
- Beacons/cones on construction sites should be equipped with good reflective materials/stickers and with a sufficient size for a good detection rate by computer vision even in rain and at night.

7. General Comments

- The MUTCD as a standard shall be the used consistently throughout all states.
- Centralized database:
- Centralized database for construction sites, road incidents, road closures, natural disasters affecting roadways.
- Database with road signs and sign location (latitude and longitude) at least for new signs.
- Reporting / database for real-time functional signal, traffic control changes or new striping
- Car accident sites on the roads should not be marked just by police signal lights (the small flare like signal lights on the road) but by bigger Standardized lights that have better visibility to computer vision making assistance of piloted cars to stop ahead on time.
- Special markers indicating the lane number to enable lane level positioning.
- We support this update effort. In addition to the update to MUTCD, we also see the need for more enforcement of existing MUTCD guidelines and any future updates. Compliance is needed to make CAT and human-driving easier.
- States implement road signs which are covered by the MUTCD but don't always fully follow its recommendation. At minimum, such differences should be notified to the public, when adopted. FHWA and the NCUTCD should collaboratively develop a process to develop an all new Appendix to the MUTCD which summarizes unique requirements from each States. For example, if and when a State adopts a road sign (or any other TCD) which are different from the recommendations of the MUTCD, FHWA could request a State to report such information to FHWA and the NCUTCD. FHWA and NCUTCD could then use this information to update the unique requirement summary database. The centralization of TCD information across the nation would be beneficial for the industry in accelerating the ADS development.
- Rail crossings - white lines for dynamic envelope & all new rail crossings must be signalized