National Committee on
Uniform Traffic Control Devices

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Item No.: 19B-MKG-02

NCUTCD Approved Changes to the Manual on Uniform Traffic Control Devices

TECHNICAL COMMITTEE:	Markings Committee
ITEM NUMBER:	19B-MKG-02
TOPIC:	Pavement Marking Standards for Automated Driving Systems and Improved Driving Safety
ORIGIN OF REQUEST:	MTC was asked to form a Task Force to review the comments from the responses to the FHWA's ADS RFI and establish if changes to Part 3 should be recommended. The FHWA ADS RFI Task Force asked for concurrence from MTC in January 2019 to vet potential changes with State DOT's, ATSSA, the Automotive Safety Council (ASC), The Auto Alliance and others.
AFFECTED SECTIONS OF MUTCD:	Sections 3A.06, 3B.04 and 3B.05 related pavement marking width, pattern and standardization

DEVELOPMENT HISTORY

- Approved by Technical Committee: 06/19/2019
- Approved by NCUTCT Council: 01/09/2020

This is a proposal for recommended changes to the MUTCD that has been approved by the NCUTCD Council. This proposal does not represent a revision of the MUTCD and does not constitute official MUTCD standards, guidance, or options. It will be submitted to FHWA for consideration for inclusion in a future MUTCD revision. The MUTCD can be revised only by the FHWA through the federal rulemaking process.

SUMMARY

The Markings Technical Committee (MTC) Automated Driving Systems (ADS) RFI Task Force has identified three areas where pavement markings can support automated driving systems: uniformity, quality, and maintenance. This proposal addresses the highest priority uniformity issues.

DISCUSSION

Pavement markings are the most often cited traffic control device that the automated driving industry references in terms of a highway infrastructure element to support the deployment of

partial to full automated driving. However, the references were often vague with inadequate details for highway agencies to assess or even implement.

The NCUTCD CAV Task Force was established approximately 3 years ago to help the NCUTCD understand how connected and automated driving technologies might impact the MUTCD. One of the key objectives of the NCUTCD CAV Task Force was to develop relationships with the vehicle industry so that the communication can improve, and both the highway and vehicle industries can collaborate more effectively in visioning a robust transportation system where both human-led vehicles and connected and automated vehicles can operate in a safe and efficient manner.

At the January 2018 NCUTCD meeting, the Markings Technical Committee formed a Task Force in anticipation of the FHWA's ADS RFI, which was designed to obtain input on roadway infrastructure requirements needed to support automated driving systems. The top finding from FHWA's ADS RFI was the need for more uniform and quality in pavement markings and other traffic control devices to support automated driving systems. Another finding from the ADS RFI was that FHWA should take a national lead in developing an understanding of how the roadway infrastructure can adapt to support automated driving systems. As a result, FHWA conducted a series of National Dialogue sessions throughout the second half of 2018 to obtain additional input. One of the key takeaways from the infrastructure-themed National Dialogue meeting was that highway infrastructure standards need to be updated to respond to automated driving systems.

The MTC RFI ADS Task Force worked with the NCUTCD CAV Task Force to review available research and engage with the automotive industry to develop specific recommendations that support automated driving systems as well as provide additional guidance and safety for human-led vehicles. Throughout the second half of 2018 and the first half of 2019, the MTC ADS RFI Task Force engaged with a variety of stakeholders to develop a thorough understanding, as well as solicit feedback and comment. Stakeholders included the AASHTO Committee on Traffic Engineering, ATSSA, the Automated Safety Council, the Auto Alliance, as well as input from six machine vision companies that provide technologies that detect and read pavement markings to provide automated driving features such as lane departure warning, lane keep assist, and lane centering. The results of these efforts were used to form the proposed MUTCD language that was presented to the MTC in June 2019. The MTC discussed and then voted unanimously to approve the proposed recommendations, as shown below, to go to Sponsors for comments.

The proposed recommendations represent the highest needs from the automated driving community. They are automotive "Original Equipment Manufacturers" (OEM's) neutral and will provide safer, more robust pavement marking detection rates resulting in fewer vehicles unintentionally leaving their lane (roadway departure crashes make up over half of all fatalities and serious injury crashes in the US).

The safety benefits from these technologies have been shown to have a much higher impact on reducing roadway departure crashes than existing infrastructure treatments such as rumble strips (for instance, a study from 2016 showed the potential to reduce fatal crashes by 29 percent once these technologies are more prevalent). And the technology is already making its way into the

vehicle fleet. In 2017, 60 percent of new vehicles sold in the US were equipped with lane departure technologies.

The proposed changes represent items mentioned, described, and/or referenced as it relates to pavement markings that support automated driving technologies—particularly the camera / machine vision systems that detect and track pavement markings for ADS features such as lane departure warning, lane keep assistance, and lane centering control. These technologies form the foundation of guidance systems used by current SAE Level 2 automated systems as well as the future, more advanced automated systems (SAE Levels 3 through 5). Engagements (meetings, presentations, and surveys) with automotive OEMs and manufacturers of ADS technologies have resulted in a vetted consensus list of priority uniformity needs that can best be addressed through changes to the MUTCD. It is expected that the proposed changes will increase safety of human drivers as well as increase the reliability of automated driving systems. For instance, FHWA research has shown that 6-inch wide edge line markings on two-lane highways can reduce fatal and injury crashes by 15 to 35 percent. Furthermore, research has shown that specific features of automated driving systems such as lane departure warning and lane keep assist, can reduce roadway departure crashes by nearly 50 percent.

Proposed changes are based on MTC Task Force recommendations that are designed to update the next MUTCD with material that is beneficial for human drivers while also assisting the vehicle technologies that enable automated driving systems. The Task Force has reviewed available research, including NCHRP 20-102(6) research, to establish recommendations for pavement marking characteristics that provide adequate machine vision detection for ADS features such as Lane Departure Warning (LDW) and Lane Keep Assist (LKA), which are already providing benefits in terms of reduced roadway departure crashes and projected to have drastic impacts on these types of crashes as more vehicles with such equipment enter the fleet (by 2025 most new car sales will include LDW and approximately half will include LKA). The recommendations are "vehicle technology neutral" as well as "markings product neutral" and provide broad societal benefits.

It is important to emphasize that this proposal is a beginning and there is still more dialogue and research needed on the items not in this proposed revision. The NCUTCD CAV Task Force and the MTC ADS RFI Task Force will continue to work together on researching and vetting the remaining uniformity issues, as well as the topics related to quality and maintenance.

Agencies who maintain pavement markings have limitations and therefore, future implementation should be when and where practical and feasible. Implementation guidance is generally described in a proposed Support statement 03a.

Additional Information:

- 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
- Responses to the FHWA ADS RFI: https://www.federalregister.gov/documents/2018/01/18/2018-00784/automated-driving-systems

- FHWA Automation National Dialogues: https://ops.fhwa.dot.gov/automationdialogue/index.htm
- Swedish Pavement Marking & Lane Departure Warning Study – 2010: http://vti.diva-portal.org/smash/get/diva2:670435/FULLTEXT01.pdf
- Roads that Cars Can Read, EuroRAP, 2011: http://www.eurorap.org/wp-content/uploads/2015/04/20110629-Roads-That-Cars-Can-Read-June-2011.pdf, and http://www.eurorap.org/wp-content/uploads/2015/03/roads_that_cars_can_read_2_spread1.pdf
- Marking the Way Towards a Safer Future (2013): https://trid.trb.org/view/1286269
- TRB Automated Vehicle Symposium, 2014 – Present: http://www.automatedvehiclessymposium.org/proceedings
- Meetings with, and presentations by, the Auto Alliance, the Automotive Safety Council and Original Equipment Manufacturers
- Pavement Marking Demonstration Projects, FHWA-HRT-12-048, November 2013: https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/12048/12048.pdf
- Road Markings for Machine Vision. NCHRP 20-102(6). Final Report Pending: https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4004

RECOMMENDED MUTCD CHANGES

The following present the proposed changes to the current MUTCD within the context of the current MUTCD language. Proposed additions to the MUTCD are shown in blue underline and proposed deletions from the MUTCD are shown in ~~red strikethrough~~. Changes previously approved by NCUTCD Council (but not yet adopted by FHWA) are shown in green double underline for additions and ~~green double strikethrough~~ for deletions. In some cases, background comments may be provided with the MUTCD text. These comments are indicated by [highlighted light blue in brackets].

PART 3. MARKINGS

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

Standard:

01 **The general functions of longitudinal lines shall be:**

- **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 line provides guidance or warning of a downstream change in lane function.**

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

- **A. Normal line — ~~4 to~~ 6 inches wide for Interstate, freeway, expressway and corresponding ramp interchange markings and for edge lines on all other roadways with posted or statutory speeds of 55 mph or more and an ADT of 6,000 vehicles per day or greater; otherwise, a normal line shall be 4 to 6 inches wide.**

B. Wide line—8 inches or more in width when used with 4 inch normal lines and 10 inches or more in width when used with 6 inch normal lines ~~at least twice the width of a normal line~~. [Approved 06-28-2014, 14B-MRK-02]

C. Double line—two parallel lines separated by a discernible space.

D. Broken line—normal line segments separated by gaps.

E. Dotted line—noticeably shorter line segments separated by shorter gaps than used for a broken line. The width of a dotted line extension shall be at least the same as the width of the line it extends.

Support:

03 The width of the line indicates the degree of emphasis.

Guidance:

04 Broken lines should consist of 10 -foot line segments and 30-foot gaps or dimensions in a similar ratio of line segments to gaps as appropriate for traffic speeds and need for delineation.

04a On Interstates, freeways, and expressways, 15-foot line segments and 25-foot gaps should be used for broken lines.

~~Support:~~

~~05 Patterns for dotted lines depend on the application (see Sections 3B.04 and 3B.08.)~~

~~Guidance:~~ **[Approved 06-28-2014, 14B-MRK-02]**

06 A dotted line for line extensions within an intersection, or taper area, or interchange ramp area (see Section 3B.12) should consist of 2-foot line segments and 2- to 6-foot gaps. A dotted line used as a lane line (see Section 3B.08) should consist of 3-foot line segments and 9-foot gaps. **[Approved 06-28-2014, 14B-MRK-02]**

~~Support:~~

~~06a the marking applications identified below have been shown to be beneficial when applied in combination with horizontal alignment warning signs to enhance safety around curves and areas with run off the road accident history:~~

~~1. Wide Edge lines~~

~~2. Delineators~~

~~3. Raised Retroreflective Pavement Markers~~

~~4. Longitudinal Rumble Strips or Stripes~~

~~5. Speed Reduction Markings,~~

~~6. Profiled Pavement Markings,~~

~~6. Other treatments with demonstrated safety benefits in reducing horizontal curve crashes such as Safety Edge, High Friction Surface Treatments~~ **[Approved 06-28-2014, 14B-MKG-02]**

Section 3B.04 White Lane Line Pavement Markings and Warrants

Standard:

01 When used, lane line pavement markings delineating the separation of traffic lanes that have the same direction of travel shall be white.

02 Lane line markings shall be used on all freeways and Interstate highways.

Guidance:

03 Lane line markings should be used on all roadways that are intended to operate with two or more adjacent traffic lanes in the same direction of travel, except as otherwise required for reversible lanes. Lane line markings should also be used at congested locations where the roadway will accommodate more traffic lanes with lane line markings than without the markings.

Support:

04 Examples of lane line markings are shown in Figures 3B-2, 3B-3, and 3B-7 through 3B-13.

Standard:

05 Except as provided in Paragraph 6, where crossing the lane line markings with care is permitted, the lane line markings shall consist of a normal broken white line.

06 A dotted white line marking shall be used as the lane line to separate a through lane that continues beyond the interchange or intersection from an adjacent lane for any of the following conditions:

- **A. A deceleration or acceleration lane,**
- **B. A through lane that becomes a mandatory exit or turn lane,**
- **C. An auxiliary lane 2 miles or less in length between an entrance ramp and an exit ramp, or**
- **D. An auxiliary lane 1 mile or less in length between two adjacent intersections.**

07 For exit ramps with a parallel deceleration lane, a normal width dotted white lane line extension shall be installed from the upstream end of the taper ~~full width deceleration lane~~ to the theoretical gore or to the upstream end of a solid white lane line, if used, that extends upstream from the theoretical gore as shown in Drawings A ~~and~~ or C of Figure 3B-8.

~~Option:~~

~~08 For exit ramps with a parallel deceleration lane, a normal width dotted white line extension may be installed in the taper area upstream from the full width deceleration lane as shown in Drawings A and C of Figure 3B-8.~~

09 For an exit ramp with a tapered deceleration lane, a normal width dotted white line extension ~~may~~ shall be installed from the theoretical gore through the taper area such that it meets the edge line at the upstream end of the taper as shown in Drawing B of Figure 3B-8.

Option:

9A For passing, climbing or truck lanes, a normal width dotted white line extension may be installed as shown in "Figure 2A-5" to guide slower-moving traffic to the right lane. **[Approved 01-08-2016, 15B-RW-01]**

Standard:

10 For entrance ramps with a parallel acceleration lane, a normal width dotted white lane line shall be installed from the theoretical gore or from the downstream end of a solid white lane line, if used, that extends downstream from the theoretical gore~~, to a point at least one-half the distance from the theoretical gore~~ to the downstream end of the acceleration taper, as shown in Drawing A of Figure 3B-9.

Option:

~~11 For entrance ramps with a parallel acceleration lane, a normal width dotted white line extension may be installed from the downstream end of the dotted white lane line to the downstream end of the acceleration taper, as shown in Drawing A of Figure 3B-9.~~

12 For entrance ramps with a tapered acceleration lane, a normal width dotted white line extension may be installed from the downstream end of the channelizing line adjacent to the through lane to the downstream end of the acceleration taper, as shown in Drawings B ~~and~~ or C of Figure 3B-9.

Standard:

13 A wide dotted white lane line shall be used:

A. As a lane drop marking in advance of lane drops at exit ramps to distinguish a lane drop from a normal exit ramp (see Drawings A, B, and C of Figure 3B-10),

B. In advance of freeway route splits with dedicated lanes (see Drawing D of Figure 3B-10),

C. To separate a through lane that continues beyond an interchange from an adjacent auxiliary lane between an entrance ramp and an exit ramp (see Drawing E of Figure 3B-10),

D. As a lane drop marking in advance of lane drops at intersections to distinguish a lane drop from an intersection through lane (see Drawing A of Figure 3B-11), and

E. To separate a through lane that continues beyond an intersection from an adjacent auxiliary lane between two intersections (see Drawing B of Figure 3B-11).

Guidance:

14 Lane drop markings used in advance of lane drops at freeway and expressway exit ramps should begin at least 1/2 mile in advance of the theoretical gore.

15 On the approach to a multi-lane exit ramp having an optional exit lane that also carries through traffic, lane line markings should be used as illustrated in Drawing B of Figure 3B-10. In this case, if the right-most exit lane is an added lane such as a parallel deceleration lane, the lane drop marking should begin at the upstream end of the full-width deceleration lane, as shown in Drawing C of Figure 3B-8.

16 Lane drop markings used in advance of lane drops at intersections should begin a distance in advance of the intersection that is determined by engineering judgment as suitable to enable drivers who do not desire to make the mandatory turn to move out of the lane being dropped prior to reaching the queue of vehicles that are waiting to make the turn. The lane drop marking should begin no closer to the intersection than the most upstream regulatory or warning sign associated with the lane drop.

17 The dotted white lane lines that are used for lane drop markings and that are used as a lane line separating through lanes from auxiliary lanes should consist of line segments that are 3 feet in length separated by 9-foot gaps.

Support:

18 Section 3B.20 contains information regarding other markings that are associated with lane drops, such as lane-use arrow markings and ONLY word markings.

19 Section 3B.09 contains information about the lane line markings that are to be used for transition areas where the number of through lanes is reduced.

Standard:

20 Where crossing the lane line markings is discouraged, the lane line markings shall consist of a normal or wide solid white line.

Option:

21 Where it is intended to discourage lane changing on the approach to an exit ramp, a wide solid white lane line may extend upstream from the theoretical gore or, for multi-lane exits, as shown in Drawing B of Figure 3B-10, for a distance that is determined by engineering judgment.

22 Where lane changes might cause conflicts, a wide or normal solid white lane line may extend upstream from an intersection.

23 In the case of a lane drop at an exit ramp or intersection, such a solid white line may replace a portion, but not all of the length of the wide dotted white lane line.

Support:

24 Section 3B.09 contains information about the lane line markings that are to be used for transition areas where the number of through lanes is reduced.

Guidance:

25 *On approaches to intersections, a solid white lane line marking should be used to separate a through lane from an added mandatory turn lane.*

Option:

26 On approaches to intersections, solid white lane line markings may be used to separate adjacent through lanes or adjacent mandatory turn lanes from each other.

27 Where the median width allows the left-turn lanes to be separated from the through lanes to give drivers on opposing approaches a less obstructed view of opposing through traffic, white pavement markings may be used to form channelizing islands as shown in Figure 2B-17.

28 Solid white lane line markings may be used to separate through traffic lanes from auxiliary lanes, such as an added uphill truck lane or a preferential lane (see Section 3D.02).

29 Wide solid lane line markings may be used for greater emphasis.

29A A curved transition may be used where an edge line, channelizing line, or dotted extension line changes direction.

Support:

29B Examples of location where a curved transition can have value include freeway exit and entrance ramps, and turn lanes. **[Approved 06-22-2012, 12A-MRK-03]**

Standard:

30 Where crossing the lane line markings is prohibited, the lane line markings shall consist of a solid double white line (see Figure 3B-12).

[In the following Figures, remove the word “optional” for the dotted edge line extensions through the exits and entrances.]

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

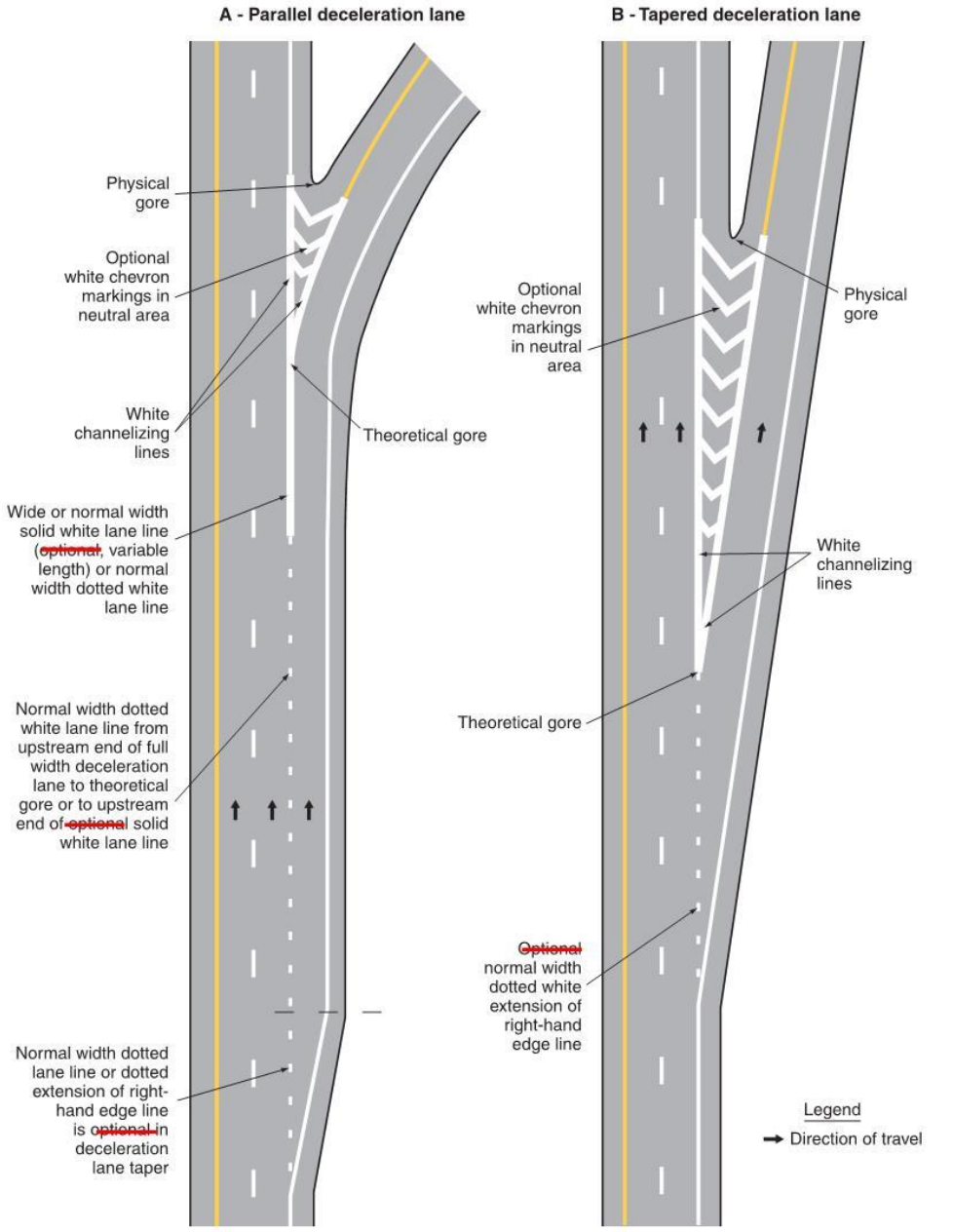

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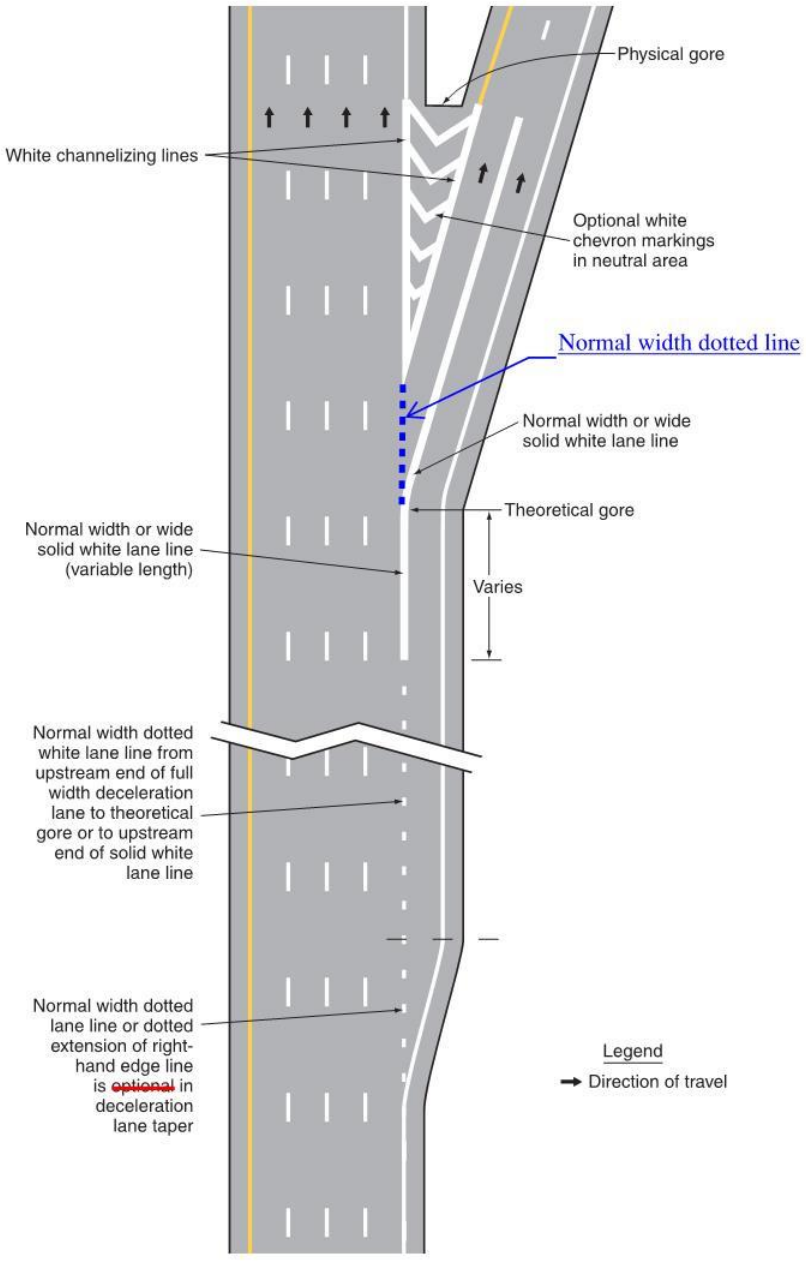
Figure 3B-8. Examples of Dotted Line and Channelizing Line Applications for Exit Ramp Markings (Sheet 2 of 2)

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



Section 3B.05 Other White Longitudinal Pavement Markings

Standard:

01 A channelizing line shall be a wide or double solid white line.

Option:

02 Channelizing lines may be used to form channelizing islands where traffic traveling in the same direction is permitted on both sides of the island.

Standard:

03 Other pavement markings in the channelizing island area shall be white.

Support:

04 Examples of channelizing line applications are shown in Figures 3B-8, 3B-9, and 3B-10, and in Drawing C of Figure 3B-15.

05 Channelizing lines at exit ramps as shown in Figures 3B-8 and 3B-10 define the neutral area, direct exiting traffic at the proper angle for smooth divergence from the main lanes into the ramp, and reduce the probability of colliding with objects adjacent to the roadway.

06 Channelizing lines at entrance ramps as shown in Figures 3B-9 and 3B-10 promote orderly and efficient merging with the through traffic.

Standard:

07 For all exit ramps and for entrance ramps with parallel acceleration lanes, channelizing lines shall be placed on both sides of the neutral area (see Figures 3B-8 and 3B-10 and Drawing A of Figure 3B-9).

08 For entrance ramps with tapered acceleration lanes, channelizing lines shall be placed along both sides of the neutral area to a point at least one-half of the distance to the theoretical gore (see Drawing C of Figure 3B-9).

Option:

09 For entrance ramps with tapered acceleration lanes, the channelizing lines may extend to the theoretical gore as shown in Drawing B of Figure 3B-9.

10 White chevron crosshatch markings (see Section 3B.24) may be placed in the neutral area of exit ramp and entrance ramp gores for special emphasis as shown in Figures 3B-8 and 3B-10 and Drawing A of Figure 3B-9. The channelizing lines and the optional chevron crosshatch markings at exit ramp and entrance ramp gores may be supplemented with white retroreflective or internally illuminated raised pavement markers (see Sections 3B.11 and 3B.13) for enhanced nighttime visibility.