Designing for Consistency: Matching Applications to Scenarios in the Use of Pavement Markings and Delineation

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TRB-STYLE-CONFOMRING WORD COUNT

WORDS	3,715	3,715
TABLES	1	250
FIGURES	7	1,750
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ABSTRACT

One elemental characteristic of an effective traffic control device (TCD) is its exclusive use under a specific set of circumstances. For example, right-hand curves are treated solely with signs that point to the right, never to the left. Scenario-based implementations, where the selection of a device is predicated on both the geometric conditions present and the message of the selected TCD, is essential for ensuring that the devices convey a clear and simple meaning and are readily understood and applied by road users.

Geometric design plays an important role in the application of TCDs within a system. TCD selection and implementation is dependent on the horizontal and vertical design criteria, roadside appurtenances, the type, location, and magnitude of transition elements such as lane reduction tapers, and even the width of lanes. In recent practice, two trends have emerged that threaten the “readability” of geometric design features and dilute the meaning and effectiveness of TCDs. On one hand, TCDs with a single meaning are being used across locations with differing geometric design characteristics. On the other hand, locations with identical or similar geometric design characteristics are being treated with TCDs that vary by location. Both of these misapplications of TCDs violate the key principle of driver expectancy. This paper identifies field cases of TCD misapplication, assesses the influence of geometric design in the selection of TCDs, and proposes model guidelines for geometric design processes and TCD implementation for practitioners who wish to achieve TCD consistency with geometric design.

BACKGROUND

As the transportation system in the United States continues to grow and develop, the need for skilled technical staff to evaluate, design, and install traffic control devices (TCDs) also increases. While the basic applications of many TCDs has not changed, complex roadway geometric design features and alternative intersection designs have necessitated new approaches to the design and installation of signs and pavement markings. One straightforward example is the "trap lane" (see pages 5-6), once relegated to urban areas yet now ubiquitous, even on rural two-lane highways. Various methods of marking trap lanes exist in practice today and signing for trap lanes is inconsistent between jurisdictions and, in administrative regions without a traffic engineer on staff, nonexistent.

Diverging diamond interchanges, roundabouts, and new approaches to traffic calming, intersection channelization, and other measures designed to reduce speed or restrict access often necessitate the installation of traffic signing and pavement markings not specifically addressed in publications such as the *Manual on Uniform Traffic Control Devices* (*MUTCD*) *(1)* or the *Standard Highway Signs* catalog (*SHS*) *(2)*, both published by the Federal Highway Administration of the United States Department of Transportation. The companion to this paper, "Designing for Consistency: Matching Applications to Scenarios in the Use of Traffic Signing" *(3)*, describes how the implementation of traffic signing can lead to inconsistent road user expectations, diluting the meaning and effect of traffic control devices. This paper continues the discussion, addressing the effects of inconsistency as related to pavement markings and delineation.

INTRODUCTION

The intention of this paper is to present the concepts related to ad-hoc case studies, undertaken in this research, of inconsistent applications of TCDs. In general, the graphical presentation of these concepts, including numerous photographs and site sketches, is intended for the podium session in which the paper will be presented. This is done in an effort to preserve the readability of this document and to conserve the time and effort associated with assembling this document.

This paper is prepared in an effort to address the issue of awareness of geometric design and its relationship to TCD selection and placement. This awareness among traffic engineering practitioners and general transportation management personnel is certainly found to be lacking, as one must only look at a few case studies to recognize that inconsistent applications of TCDs exist and are likely to have a detrimental effect on traffic operations and safety. Beyond addressing the awareness of these trends, proposed changes to existing practice and a discussion of needed future research are provided, with the intention of starting a conversation.

This paper discusses addressing inconsistency by means of matching applications to scenarios in the deployment and design of traffic control devices, emphasizing the relationships of pavement markings and delineation to geometric design. As in the case of traffic signing, two forms of inconsistent application are typically observed in the field when pavement markings are considered. These inconsistencies can be thought of one-to-many relationships and many-to-one relationships; they relate to another common problem particularly plaguing delineation, the inconsistency of maintenance activities.

In the first circumstance, the one-to-many relationship, a TCD with a single meaning is being used across locations with differing geometric design characteristics. This can be described as a *broadening usage*, that is, the application of a TCD beyond the specific case or specific set of related cases for which it was intended. An example of this broadening usage would be the use of the DO NOT ENTER sign is places where some vehicles, but not all vehicles, are permitted to enter. On its face, this application may seem rather benign but it could potentially lead to an erosion of motorist respect for the DO NOT ENTER sign and perhaps the assumption that DO NOT ENTER signs are not to be uniformly obeyed as they do not always indicate that a wrong-way movement is about to occur. Relative to pavement markings, the use of dotted lane lines, typically confined to longitudinal markings in advance of exit only lanes, is spreading to other locations where different types of lane terminations occur.

In the second circumstance, the many-to-one relationship, locations with identical or similar geometric design characteristics are being treated with TCDs that vary by location. This can be described as *erratic usage*, that is, the application of TCDs with differing meanings in locations where one or a discrete set of TCDs should be consistently employed. An example of erratic usage is readily observable in the treatment of lane reductions with lane reduction arrows, where arrow designs with various degrees of effectiveness are used or not used.

The broadening usage and the erratic usage both lead to inconsistent road user expectations. Some practitioners argue that prescribing specific use cases for TCDs and indicating clear designs in the *MUTCD* is some type of a "secret code" that only practitioners will know and that few will practice. This viewpoint fails to consider that consistently-applied TCD treatments, with narrow use cases and uniform applications, will lead to road users adapting to the treatments, recognizing the relationships, and reacting appropriately when presented with information in the form of TCD treatments.

DISCUSSION

The use of pavement markings in situations not specifically described in the *MUTCD* demands that a practitioner be especially skilled in understanding how drivers perceive the markings, the behavioral responses to certain marking deployments, and the importance of maintaining consistency of width, color, and pattern between applications. This is critical not only for pavement markings consisting of longitudinal and transverse lines, but also markings created with point markers such as raised reflective pavement markers and barriers created by means of delineator posts.

The design of pavement markings and even the standard plans of agencies can exhibit features that run contrary to conventional practices intrinsic to the most basic human factors evaluations. Some common errors are described in the following list:

- Insufficient distinction between patterns for dotted extension lines and dotted lane lines
- Patterns of reflective pavement markers that are not progressive
- Use of white pavement markings and delineators on the left side of one-way facilities
- Use of yellow pavement markings between travel lanes moving in the same direction
- Incorrect use of angled transverse markings when chevron markings are required
- Broadening usage of pavement marking patterns, such as the use of dotted lane lines in multiple scenarios
- Erratic usage of pavement marking patterns, such as the use of dotted extension lines in places where dotted lane lines would be appropriate

Pavement Marking Patterns

Pavement marking patterns play and important role in providing road users with information concerning the status of a lane, whether continuing or not, whether there is a transition taper or not, and even the type of restriction in the lane or restrictions with regard to movement into and out of the lane. Of equally-critical importance is the maintenance of markings, especially in areas where snow and precipitation are common, something undertaken to a higher degree of success in Europe, for example.

In general, on roadway facilities, there are six distinct classes of pavement marking pattern applications, outlined in Table 1.

Pattern	Typical Dimension	Use
Broken Lane Line	10’ LINE / 30’ SPACE 3.3-m LINE / 9.9-m SPACE	separates two continuing lanes
Dotted Lane Line	3’ LINE / 12’ SPACE 0.9-m LINE / 3.6-m SPACE	separates a continuing lane from a non-continuing lane subject to a downstream mandatory movement
Dotted Extension	2’ LINE / 6’ SPACE 0.6-m LINE / 1.8-m SPACE	separates a full-width lane from an area of transition, such as a lane development taper for a turn lane, a lane reduction taper, or between turning lanes within an intersection
Solid Line	SOLID	separates a continuing lane from a non-travel lane such as a shoulder or, when wider, separates a continuing lane from a non-continuing auxiliary lane such as a turn lane or other mandatory movement lane or separates lanes designed for restricted use
Double Solid Line	SOLID	separates lanes where crossing from either side is prohibited
Solid Line with Broken or Dotted Lane Line	MIXED	separates lanes where crossing from one side is permitted but crossing from the solid side is prohibited

TABLE 1 Pavement Marking Patterns and Typical Uses

The typical uses of pavement marking patterns here can be applied to various scenarios of continuing, non-continuing, and terminating lanes, using patterns in conjunction with each other, perhaps even in double-line configurations.

In addition to width, color and pattern, the texture of the pavement marking can also be important. In regions with limited snow removal activities, the use of textured and profiled markings has been found to be an effective replacement for non-reflective raised pavement markers. These profiled markings cause a tactile sensation for road users and the use of these markings, particularly in conjunction with roadside delineation, can be an effective mitigation against roadway departure crashes.

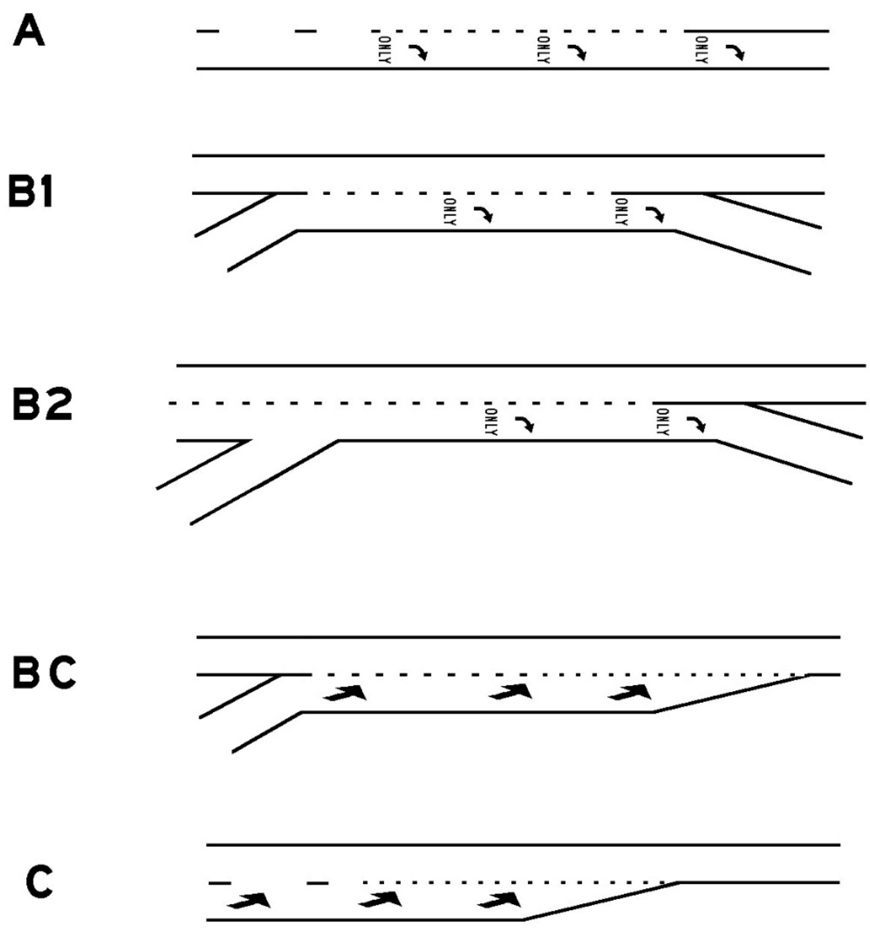


FIGURE 1 Configurations of Exiting and Entering Lanes

The figure above illustrates several different geometric design features. Comparing Depictions B1 and BC of Figure 1, for example, reveals that, from the road user perspective, the entrance ramp joins the mainline roadway as an exclusive lane. In Depiction B1, the entering traffic occupies an auxiliary lane which terminates in a downstream exiting movement. In Depiction BC, the entering traffic occupies an acceleration lane which terminates in a lane reduction taper.

An emerging practice in many states is to use the dotted lane line for the geometry in Depiction B1 and Depiction BC. In heavy traffic, particularly in cases where the acceleration lane taper is of significant length, motorists may mistake the acceleration lane (BC) for an auxiliary lane (B1) and may fail to vacate the acceleration lane. Road users on the major facility may similarly mistake the lane and move into it, not realizing that the lane terminates. Even the use of lane reduction warning sign and lane reduction arrows may be insufficient in heavy traffic, especially if auxiliary lanes are generally provided.

Dotted Extensions and Dotted Lane Lines

Preserving a distinction between these two patterns is critical to the effort engineers should undertake to provide consistency among usage cases. The Wisconsin Department of Transportation, for example, uses the same marking cycle for all dotted lines, regardless of the intended use. Other Departments of Transportation have preserved the marking pattern for dotted lane lines that specifies a 12-foot (3.6-metre) gap, as opposed to a 9-foot (2.7-metre) gap, recognizing the importance of that larger ratio in preserving this distinction between the dotted extension marking pattern and dotted lane line marking pattern, especially when coupled with the use of wider lines for dotted lane line installations.

Comparison of the dotted lane line and dotted extension line applications in Depiction BC of Figure 1 reveals how the change in pattern is an effective way to indicate that the lane is approaching its termination point. The exclusive use of the dotted extension, that is, avoiding broadening usage cases, will ensure that road users interpret it as indicating an area of transition, a taper forming a lane or terminating a lane. In Figure 2, the same marking pattern is used along the entire length of the left-hand acceleration lane, a left entrance from another freeway. The lack of advance lane reduction arrows, roadside delineation, and signing for the lane reduction taper could be mitigated with a transition in pavement markings, a cue to road users that the status of the lane is changing.

FIGURE 2 Acceleration Lane Terminating in a Lane Reduction Taper

Raised Reflective Pavement Markers

While a change in marking patterns is useful to motorists, a change in the marking patterns may prove detrimental if the change is not progressive. Examining the transition from a broken lane line to a dotted lane line to a dotted extension, for example, leads to the conclusion that the pattern becomes visually more restrictive as the road user moves through the patterns. When Raised Reflective Pavement Markers (RRPMs) are placed, their installation cycles typically correspond with the associated longitudinal pavement markings. Longer spacing between RRPMs is logically associated with a less restrictive marking, missing markers notwithstanding. In fact, most agencies do not use RRPMs in transition areas, those being the development tapers of turn lanes and the termination tapers associated with lane reductions. Even if those areas are marked with dotted extension lines, the markers are omitted, partially to preclude the intensive replacement cycle due to traversing traffic but also because movement across those areas is encouraged, when desired by the navigation and piloting directives of the road users.

The Washington State Department of Transportation uses substitutionary markers for pavement markings in some cases, typically consisting of round 4” (250 mm) non-reflective domed markers and RRPMs. Comparison of the double lane line marking pattern (most restrictive) and dotted lane line pattern (intended for information) in Figure 3 reveals that the less restrictive marking (the dotted lane line) features reflectors spaced at roughly half the interval of the more restrictive marking (the double lane line). A short drive along any EXIT ONLY lane reveals how disorienting and counterintuitive this marking pattern can be, especially in areas of horizontal curvature where edge lines may be supplemented with RRPMs at 20-foot (6-metre) intervals as well.

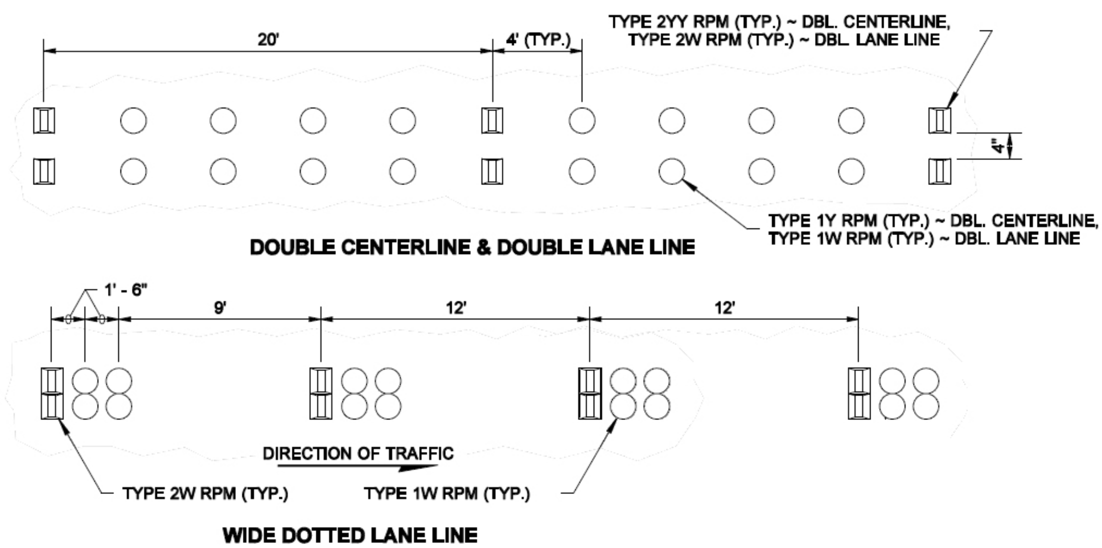


FIGURE 3 Excerpt from WSDOT Standard Plan M20.50-02

Marking Intersections

The majority of urban crashes occur at intersections. Intersection crashes are generally seen as being related to signalized intersections and failure to yield right-of-way but some types of intersection crashes, particularly sideswipe crashes, can be attributed to missing, unclear, or incorrect pavement markings.

Pavement markings approaching and within intersections must provide information to the user concerning lane assignments, lane use restrictions, guidance through the intersection in addition to providing corrective information concerning wrong-way movements and non-traversable areas.

Solid Lines on the Approaches to Intersections

Pavement marking pattern plays a critical role in helping users identify the use and restrictions associated with a lane. Within intersections, this is even more critical, as abrupt lane changes are a contributing factor in crashes. Paragraph 1 of the Support statement in Section 4D.35 of the *MUTCD*, titled Use of Pavement Markings at Signalized Locations, reads as follows:

> "Pavement markings (see Part 3) that clearly communicate the operational plan of an intersection to road users play an important role in the effective operation of traffic control signals. By designating the number of lanes, the use of each lane, the length of additional lanes on the approach to an intersection, and the proper stopping points, the engineer can design the signal phasing and timing to best match the goals of the operational plan."

FIGURE 4 Solid Lines on an Intersection Approach

The solid line depicted in Figure 4 appears to be a lane line. In this particular scenario, there is a single lane approaching the intersection and, in this region, where dotted extension lines are seldom used, even the entrance to the left turn lane appears to be a through lane on account of the centerline shifting taper associated with the upstream roadway alignment. Motorists hesitate to enter the right-most lane, unsure of whether it is a through lane or a mandatory turning lane.

Further complicating matters, this intersection is offset with a right-hand shift for traffic moving in the direction of the photo. Application of pavement markings to create a splitter median between the left turn lane and the two through lanes, making them equal width, would eliminate the need for transition markings within the intersection and reduce the width of the right lane, providing a safety benefit to bicyclists. In conjunction with such an improvement, the solid line dividing the two through lanes would be replaced with a broken lane line.

FIGURE 5 Approach View in an Intersection with a Right-Hand Shift Offset

Dotted Extensions within Intersections

This particular intersection experienced crash problems related to the offset. Marking the through lanes across the intersection would identify that there is a lane pair and match the colors on the approach and departure legs. In this case, however, the white dotted extension markings begin at the downstream end of the lane line separating the left turn lane from the left-hand through lane and terminate at the yellow edge line on the far side of the intersection. This may lead drivers to perceive that the left turn lane is a through lane (in the absence of any lane use control signs) and it also violates a diver expectancy related to marking position and color. A remedy to this situation would be to place the extension line between the two through lanes, clearly delineating the path of two lanes and clearly indicating the application of a marking pattern typically intended for the adjacent lanes only.

FIGURE 6 Dotted Extension Leading from Solid Lane Divider Line to Yellow Left Edge Line on Departure Leg

SUGGESTED FUTURE RESEARCH

This paper has presented examples of inconsistency in TCD applications. The broadening usage and erratic usage cases cited are indicative of practitioner inexperience and a lack of familiarity with human factors principles in design and operations. In some cases, it appears that expediency and TCD availability are valued over clarity and consistency. In other cases, it is apparent that spatial and temporal influences have brought about inconsistency in TCD applications. Careful study of these cases is necessary to determine how to best address the issue and tailor resources to specific problems.

Field and Laboratory Research Needs

Addressing the broadening usage and erratic usage cases would best be done by continuing and increasing the activities of NCHRP and other research program synthesis activities, particularly those related to identifying gaps in practice and practice applications that portend inconsistency within administrative regions and non-compliance with existing prevalent practices and/or the *MUTCD*.

As this synthesis research is carried out, it is likely that some studies will indicate the need to carry out additional data collection, human factors studies, and other activities typically undertaken as part of the research activities of the NCHRP and various pooled-fund study efforts. In many cases, research may indicate a preferred practice. Whether or not this is the end result of research activities, it is imperative that root cause analysis be employed to determine the reason for inconsistencies. Changes in policy, procedures, and work activities may address some issues. In some states, for example, the use of certain sign "cutting" software has resulted in traffic sign arrows that do not conform to the *Standard Highway Signs* manual published by the FHWA. State DOT-level policy memorandums and FHWA advisory circulars, similar to those used by the Federal Aviation Administration, could caution against certain practices and indicate corrective measures to ensure an improved level of consistency in in the design and fabrication of traffic signing. Such an approach would address all the vertical components of the contract delivery process, particularly subcontractors and contractors with limited experience and staff technical aptitude.

Technical Training

Ensuring consistency in design activities, particularly within an agency, can be achieved by means of training activities and technical specialty certification programs led by technically-proficient expert designers. In the case of guide sign design in particular, the inexperience of practitioners without a human factors background or strong apprenticeship in traffic sign design could be partially mitigated with training programs. However, these training programs will be ineffective if led by contractors or personnel who are not first top-of-the field practitioners. In the opinion of the authors, training and technical certification programs are a key path toward correcting long-term deficiencies in the workforce development of technically-proficient staff, as many lack mentors and work experience with skilled designers, owing to industry-wide trends related to retirements of government agency employees.

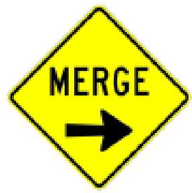
Users of the *MUTCD*

One means of reaching more practitioners with more practical knowledge is to combine the technical and regulatory information of the *MUTCD* with additional information related to TCD typical applications, field installations, and policy best practices. A potential means of distributing this information is the TCD "Fact Sheet", a document which would provide information specific to a TCD, traffic control strategy, TCD system, or other discrete element. In referencing Figure 7, a user would also choose to examine a Typical Application diagram that addresses lane reduction transitions.

Manual on Uniform Traffic Control Devices — Section 2C.42
2016 Edition — Lane Reduction Warning Signs

W9-2 Lane Ends Hybrid Symbol Signs

W9-2L



W9-2R

Information

The Lane Ends hybrid symbol sign is intended for use in advance of the lane reduction taper where a reduction in the number of lanes, either through lanes or auxiliary lanes, is accomplished by means of a lane reduction taper. The Lane Ends Hybrid Symbol sign is intended to be used downstream of and in conjunction with the RIGHT (LEFT) LANE ENDS sign (W9-1) or the Lane Reduction symbol sign (W4-2) where continuous lanes are ending. Alternatively, this sign may also be used alone in locations, such as short acceleration lanes, where the other advance warning signs cannot be provided.

The Lane Ends hybrid symbol sign is intended for placement just prior to the beginning of the lane reduction taper. Generally, the placement will be at the beginning of the lane reduction taper or in advance of the beginning of the lane reduction taper by a distance equal to no more than a multiple of 1.5 times the posted speed limit. Uniform placement between multiple locations in similar facility types is desirable.

Policy

Standard — **The Lane Ends hybrid symbol sign shall not be used in advance of any other lane reduction advance warning sign.**

Guidance — Use of the Lane Ends hybrid symbol sign should be standardized between locations of similar geometric and operational conditions.

Option — The Lane Ends hybrid symbol sign may be installed in advance of the beginning of lane reduction tapers to warn motorists that the subject lane is ending and that a taper will begin at the location of or closely following the sign.

History

The Lane Ends Hybrid Symbol sign was developed for use in work zones by the Minnesota Department of Transportation. Use of the sign in permanent installations was tested in 2009 and its use expanded to several other states. This sign was first included in the 2016 Edition of the MUTCD.

Succession

This sign replaces the LANE ENDS MERGE LEFT (RIGHT) sign, which last appeared in the 2009 edition of the MUTCD.

References

W4-2 Lane Reduction Symbol Sign (Section 2C.42)
W9-1 RIGHT (LEFT) LANE ENDS Sign (Section 2C.42)
Pavement Markings for Transition Areas (Section 3B.08)
Typical Applications of Lane Reductions (Figure 2C-9)

FIGURE 7 “Fact Sheet” Sample (Typical Publication of Material from Database) *(4)*

This type of presentation of information is very similar to what one might find when presented with a "cut sheet" or product specifications guide. In fact, when mechanical engineers select bolts, bar, and chain for use in projects, they often refer to large catalogs containing basic information for an individual device or product. Key sections in the Fact Sheet are clearly displayed to ensure that information is easily accessible.

Title and Header

The title references the corresponding *MUTCD* Section and includes device-specific nomenclature to ensure that each Fact Sheet is easily comprehensible and clearly defined.

Depiction

The depiction displays the general appearance of the TCD. Display of solely the subject sign helps provide clarity as current warning sign figures in Chapter 2C of the *MUTCD* show related signs, often not in proximity to any related text and often without any order related to their use.

Information

Basic background on the use, function, and general safety performance of the subject TCD or system is provided in the Information portion of the Fact Sheet. Despite not being subject to the rulemaking process, this content is essential to aiding user understanding of the importance of the device, its function in any larger group or system of devices, and potential pitfalls associated with its use.

Policy

This portion of the Fact Sheet contains only that information which was subject to rulemaking. The policy statements follow those included in the *MUTCD* and, in the future, may also include other levels of mandate, such as those described in the NCUTCD's *Strategic Plan*. Documentation associated with the Fact Sheets would call attention to the necessity of compliance with all Policy statements, to the extent required by statute.

History

A general history of the subject device or system is provided, based on metadata and a fields entered related to device history.

Succession

Often, devices are introduced that replace other devices and, more rarely, a device will experience a lapse in *MUTCD* inclusion. The ability of users to see the relationship of new devices to those that have been phased out permits immediate recognition of the need for device replacement and the identification of the appropriate device.

References

This section references internal content and content in related publications that are named in the *MUTCD*'s Related Publications List (Section 1A.11), in addition to including references to available research that formed the basis of FHWA and policy advocacy organization recommendations related to the inclusion of the subject device.

REFERENCES

[1] *Manual on Uniform Traffic Control Devices*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2009.

[2] *Standard Highway Signs*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 2004.

[3] Kuznicki, S.O. and Katz, B.J. Designing for Consistency: Matching Applications to Scenarios in the Use of Traffic Signing. Submitted for the 5th International Symposium on Highway Geometric Design. Vancouver, British Columbia, Canada, 2015.

[4] Avery, R.P. and Kuznicki S.O. Database-Driven Implementations for Future Editions of the Manual on Uniform Traffic Control Devices. TRB 14-0448, Proceedings of the 93rd Annual Meeting of the Transportation Research Board, 2014.