

USE OF PROTECTED/PERMITTED LEFT-TURN SIGNAL CONTROL IN THE U.S.

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INTRODUCTION

The growing level of traffic demand on urban and rural roadways has led to increased use of protected/permitted left-turn (PPLT) signal control. Recall that PPLT signal phasing provides an exclusive phase for left-turns as well as a permissive phase during which left-turns can be made if gaps in opposing through traffic allow, all within the same signal cycle (1). Consequently, PPLT signal phasing can improve operational efficiency at signalized intersections by increasing left-turn capacity and reducing delay. In addition, PPLT signal phasing provides the phase sequence flexibility needed for progression on arterial streets as these left-turn controls can precede (lead) or follow (lag) the through phase.

The signal display most commonly used with PPLT signal phasing is a five-section signal display with a green arrow indication for the exclusive left-turn phase and a green ball for the permitted left-turn phase. Since the Manual of Uniform Traffic Control Devices (MUTCD) does not require a separate PPLT signal display, and provides only general guidance in signal display selection, many transportation agencies use different mounting locations, signal display arrangements, and permitted indications when implementing PPLT (2). Some state and local agencies have adopted the five-section cluster display located between the through and left-turning lanes, while other agencies place a five-section horizontal or vertical PPLT signal display over the left-turn lane. In addition to signal display location and arrangement, there are at least four variations of the permitted indication including the flashing red ball, flashing red arrow, flashing yellow ball, and flashing yellow arrow. The extent of these variations, as well as the number of signalized intersections which contain PPLT signal control, is not well understood.

This paper presents the results of a comprehensive agency survey sent to local, county, and state officials designed to determine the use of PPLT signal control in the U.S. The agency survey was sent to the state traffic engineer in all 50 states and to traffic engineers in 250 of the largest city and county transportation agencies. In total, 325 surveys were distributed. The first section presents general survey information including the total number of surveys received and the total number of signalized intersections reported. This section also quantifies the number of signalized intersections containing PPLT signal displays. The second section presents the types of PPLT signal displays used by these agencies and typical signal display mounting practices. The third section presents intersection geometry and signal phasing practices most often used with PPLT signal phasing. Finally, the last section provides a brief summary of the results. The agency survey was one of 13 tasks conducted at part of the research project, NCHRP 354(02): *An Evaluation of Traffic Signal Displays for Protected/Permitted Left-Turn Control* (3).

SURVEY RESPONSE

One-hundred-eighty of the 325 surveys mailed were returned which resulted in a 55 percent response rate. Of the 180 surveys received, six surveys from Canadian agencies and six surveys from agencies that did not use PPLT signal phasing were not included in the database. At least one survey was received from each of the 50 states with Texas providing the greatest number of responses (23 responding agencies). California was second with 12 agencies responding while 14 states had only one responding agency.

A combined total of 107,219 signalized intersections were operated and maintained by the 168 agencies. As presented in Figure 1, 30,870 of the 107,219 signalized intersections (29 percent) contained PPLT signal phasing, consistent with the findings of the 1996 survey conducted by the Western Section of ITE (4).

PPLT SIGNAL DISPLAYS

The first question in this section asked respondents to quantify the number of PPLT signal displays and corresponding arrangement types currently used. These results are presented in Figure 2. The five-section cluster display represents nearly 63 percent of all PPLT signal displays. The five-section vertical display represents approximately 19 percent of all PPLT signal displays while the five-section horizontal display represents approximately 9 percent. Only the state of Texas and Dade County, Florida reported that the five-section horizontal display was predominantly used for PPLT signal phasing. Twelve states reported limited use of five-section horizontal displays. In contrast, the five-section cluster display was identified as the predominant PPLT signal display in 34 states. Those states that indicated a predominant number of four- or three-section PPLT signal displays generally use either a bi-modal yellow/green arrow indication or one of the unique flashing yellow or red permitted indications.

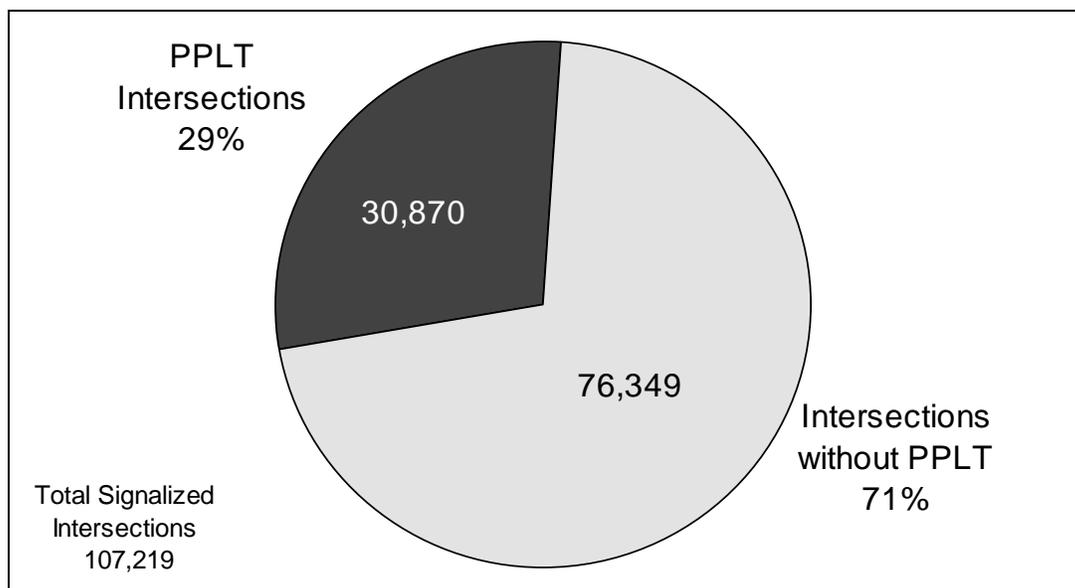


Figure 1 Total Number of Signalized Intersections with PPLT Signal Phasing.

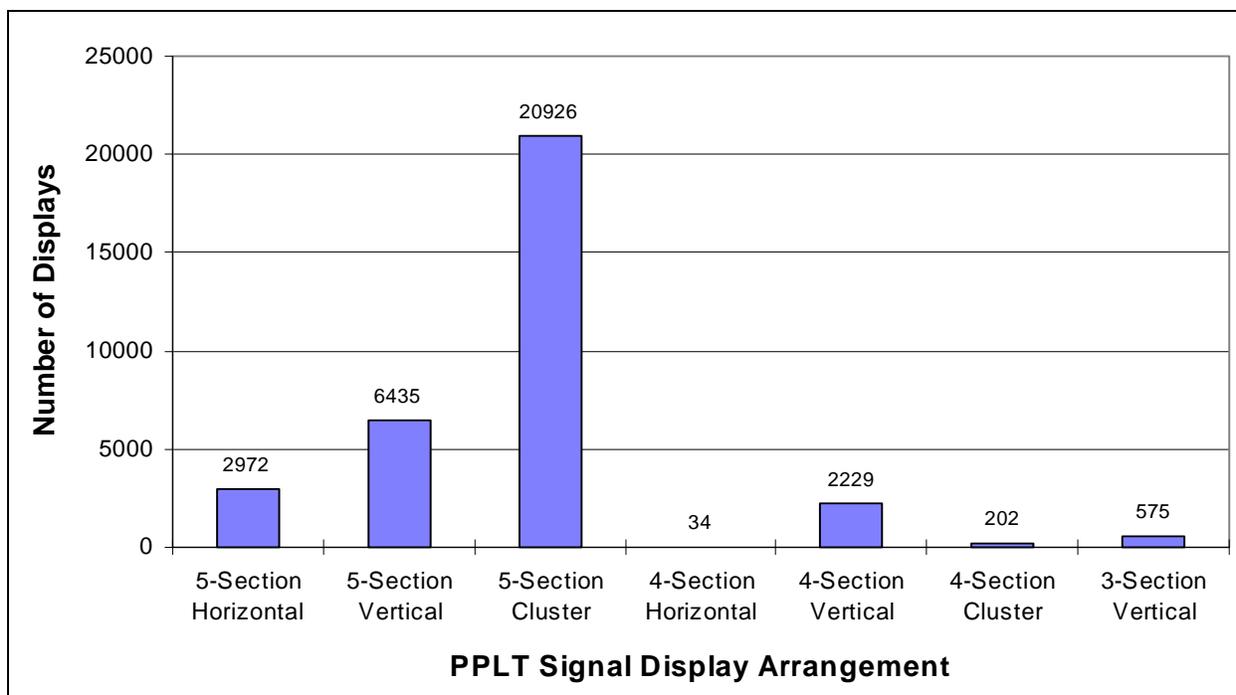


Figure 2 Distribution of PPLT Signal Display Arrangements Used.

Seventy agencies (42 percent) reported the uniform use of one PPLT signal display arrangement throughout their jurisdiction. Most of the remaining agencies use a combination of the post mounted four- or five-section vertical display in median applications with a five-section vertical or five-section cluster display with mast arm or span wire mounts. Other than Texas and Dade County, Florida, most agencies used the five-section horizontal displays only at bridges, in areas where drivers' sight distance is restricted, or other locations where clearance between the roadway and the bottom of the signal display may be limited.

The cities of Los Angeles, California, Baton Rouge, Louisiana, and Topeka, Kansas reported the use of a different PPLT signal display arrangement depending on the signal phasing sequence used. A five-section cluster (mast arm/span wire) or five-section vertical (pole mount) display is used with leading left-turn signal phasing while a four-section vertical display is used with lagging left-turn phasing. Many agencies who used multiple PPLT signal display arrangements indicated that they are moving toward uniformity, and most often, to the five-section cluster display. Only Dade County, Florida and Monroe County, New York indicated that they were moving away from the five-section cluster display to another display, in each case the five-section horizontal display.

PPLT Signal Display Mounting

The next section of the survey explored mounting methods and mounting locations used with PPLT signal displays. Figure 3 presents the relationship between mounting types and the PPLT signal display arrangement used. The cluster display is the primary display used with mast arm and span wire mounts in 103 (61 percent) and 92 (55 percent) of the 168 responding agencies,

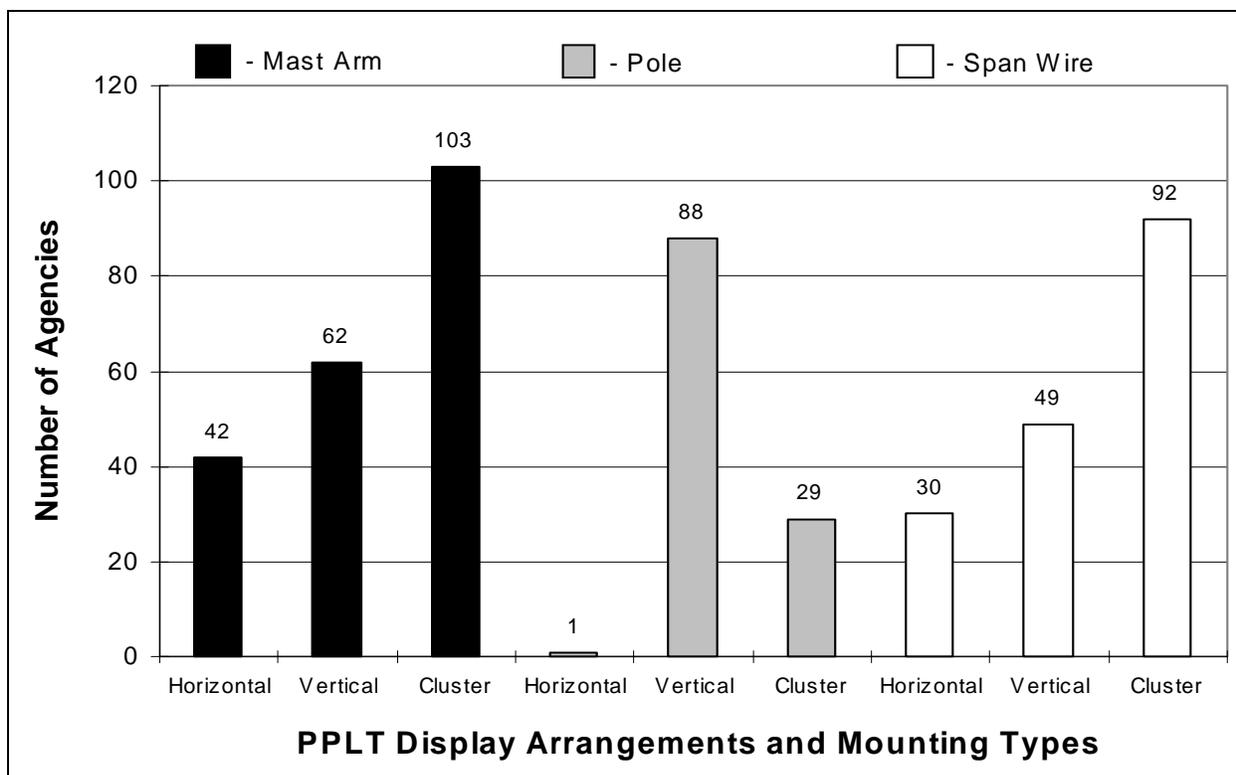


Figure 3 Signal Display Arrangements Used with Various Mounting Methods.

respectively. The vertical display is used primarily with pole mounting situations, most often in median applications. Note that only Harris County, Texas indicated that they used a horizontal display with a pole mount. In general, the relationship between the horizontal, vertical, and cluster displays used with mast arm and span wire mounting applications is consistent with the relative number of signal displays.

When using mast arm or span wire mounting methods, there was little consistency in mounting location. Fifty-two percent of responding agencies indicated that they mount the overhead PPLT signal display over the lane line between the left-turn lane and adjacent through lane. Forty percent of agencies indicated that they mount the PPLT signal display centered over the left-turn lane. The remaining seven percent generally place the PPLT signal display somewhere between the centerline of the left-turn lane and the lane line. Several agencies indicated that they place the PPLT signal display centered over the leftmost through lane. Agencies that use mast arms indicated that the exact placement of the PPLT signal display is often determined by the available length of the mast arm.

An additional evaluation was completed to explore the relationship between mounting location and display arrangement. The results are presented in Table 1. Note the large increase in the use of the five-section cluster display when the PPLT signal display is mounted between the left-turn lane and the adjacent through lane. Locations classified as *other* generally included signal display placed over the left-turn lane but not centered, or placed at some location over the inside through lane.

Table 1 Percentage of PPLT Signal Display Type Used with Each Mounting Location

Mounting Location	Total Agencies	PPLT Signal Displays						
		5-Sect.			4-Sect.			3-Sect.
		H*	V	C	H	V	C	V
Centered over Left-Turn Lane	58	26.9	30.3	33.8	0.2	4.6	0.3	4.0
Between Left-Turn and Adjacent Through Lane	78	4.2	13.2	77.3	0.0	3.4	0.6	1.2
Other	12	8.4	31.0	35.6	0.8	23.2	0.8	0.3
Varying Locations	20	0.7	18.9	65.6	0.0	13.1	0.8	0.8
All	168	8.9	19.3	62.7	0.1	6.7	0.6	1.7

H = Horizontal; V=Vertical; C=Cluster.

The next question in the survey explored the mounting location of a secondary PPLT signal display, when used. These results are presented in Figure 4. Eighty-three agencies (49 percent) indicated that they use a secondary PPLT signal display while 85 agencies (51 percent) indicated that they did not. Sixty-seven of the 85 agencies (79 percent) indicated that they place the secondary PPLT signal display on a far side pole mount. Twenty-two agencies (13 percent) indicated that they place the secondary PPLT signal display on a median pole mount and eight agencies (5 percent) use a near side pole mount location. The 11 agencies that indicated *other* in the survey response generally use a second overhead PPLT signal display either mast arm or span wire mounted.

When each agency was asked if they use a PPLT signal display as one of the two through movement signal displays required by the MUTCD, 38 agencies (23 percent) indicated that they never do, 63 agencies (37 percent) indicated that they always do, and 68 agencies (40 percent) indicated that they sometimes do. Note that Oakland County, Michigan is included twice since they indicated that they always use the five-section cluster display as one of the two required through movement displays but never use the three-section vertical display as one of the required through movement displays. Many of the agencies who indicated that they may use the PPLT signal display as a through movement display base their decision on the geometry of the roadway. Generally, if only one left-turn lane and one through lane exist, then the PPLT signal display will be used as a through movement display. If additional through lanes exist, a third signal display is added. Other agencies have made a shared PPLT signal display standard.

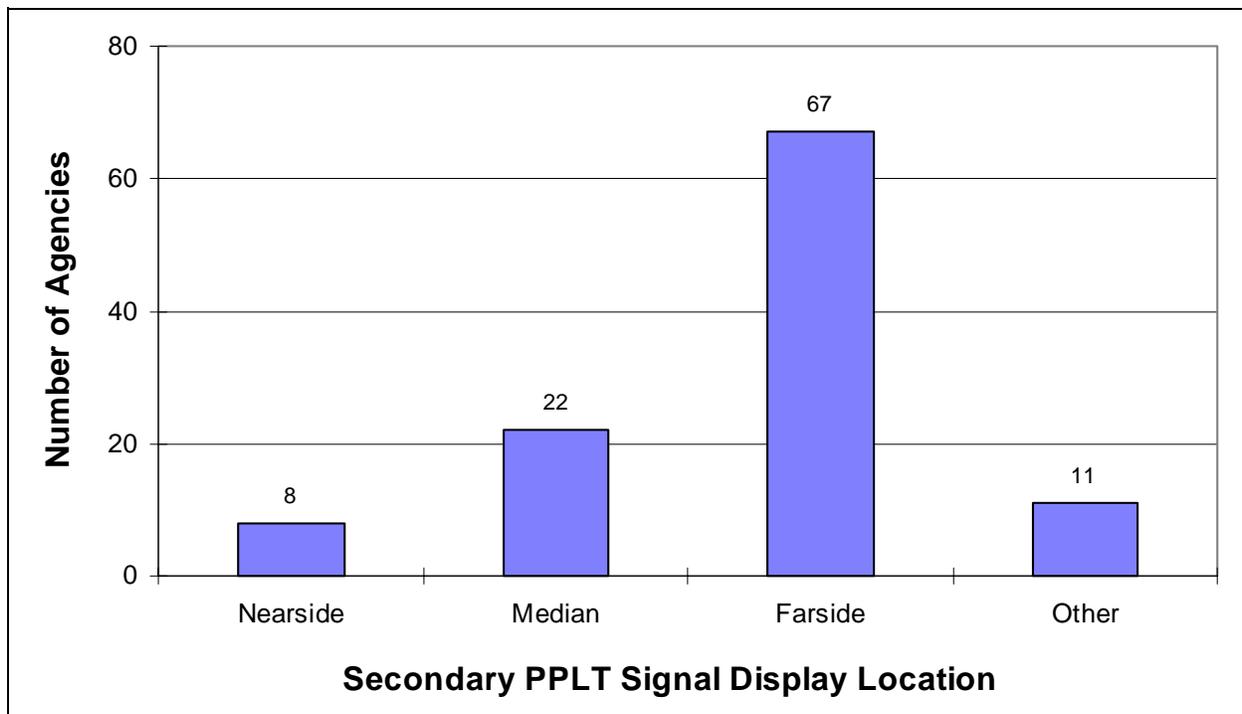


Figure 4 Mounting Location of Secondary PPLT Signal Display (When Used).

Permitted Phase Signal Indications

The next section asked agencies to report the type of permitted indication used with PPLT signal phasing. The results are presented in Figure 5. One-hundred sixty-five of the 168 responding agencies (98 percent) use the green ball indication as defined in the MUTCD. The three agencies that did not use the green ball indication were Cupertino, California (flashing red arrow), Wayne County, Michigan (flashing red ball), and Seattle, Washington (flashing yellow ball). Several agencies use multiple permitted indications. Tucson, Arizona uses a green ball and flashing yellow arrow indication. Three agencies in the Detroit, Michigan area and Broward County, Florida use the green ball and flashing red ball indication. Along with Cupertino, California, the flashing red arrow permitted indication is used in the Dover, Delaware area and in Maryland. The Newfoundland Department of Public Works in St. Johns Newfoundland, Canada was the only transportation agency which indicated the use of a flashing green arrow indication; however, this indication was used for the protected left-turn phase.

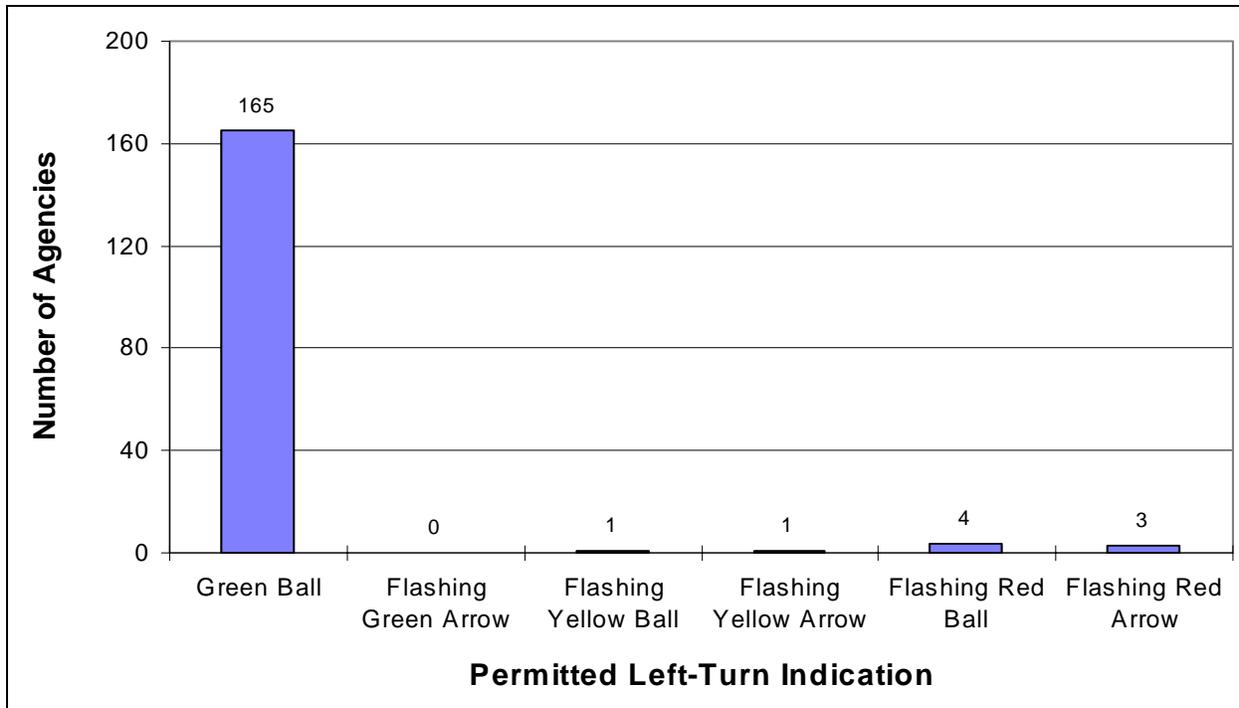


Figure 5 Signal Indication Used for the Permitted Phase of PPLT Signal Phasing.

Supplemental Signs

The next section asked agencies to indicate if they use supplemental signs with PPLT signal displays, and if so, which supplemental signs did they employ. The results of the first part of this question is shown in Figure 6. Eight-two agencies (49 percent) indicated that supplemental signs are always used with PPLT signal phasing while 28 agencies (17 percent) indicated that supplemental signs are never used. Fifty-two agencies (31 percent) indicated that supplemental signs are used under certain conditions, but not in all cases, and seven agencies (4 percent) indicated that different supplemental signs are used for different conditions. Cupertino, California indicated that they always use supplemental signs, but use different signs for different conditions.

The type of supplemental signs used are shown in Figure 7. The PROTECTED LEFT ON GREEN ARROW sign was used by five percent of the agencies (all in Texas), the LEFT TURN SIGNAL sign by seven percent of the agencies, the LEFT TURN SIGNAL - YIELD ON GREEN (ball) sign by four percent of the agencies, the LEFT TURN YIELD ON GREEN (ball) sign by 76 percent of the agencies, and some *other* supplemental sign by nine percent of the agencies. Table 2 presents the *other* supplemental signs reported. Note that the MUTCD indicates that only the LEFT TURN YIELD ON GREEN (ball) sign (R10-12) should be used with PPLT signal phasing (2).

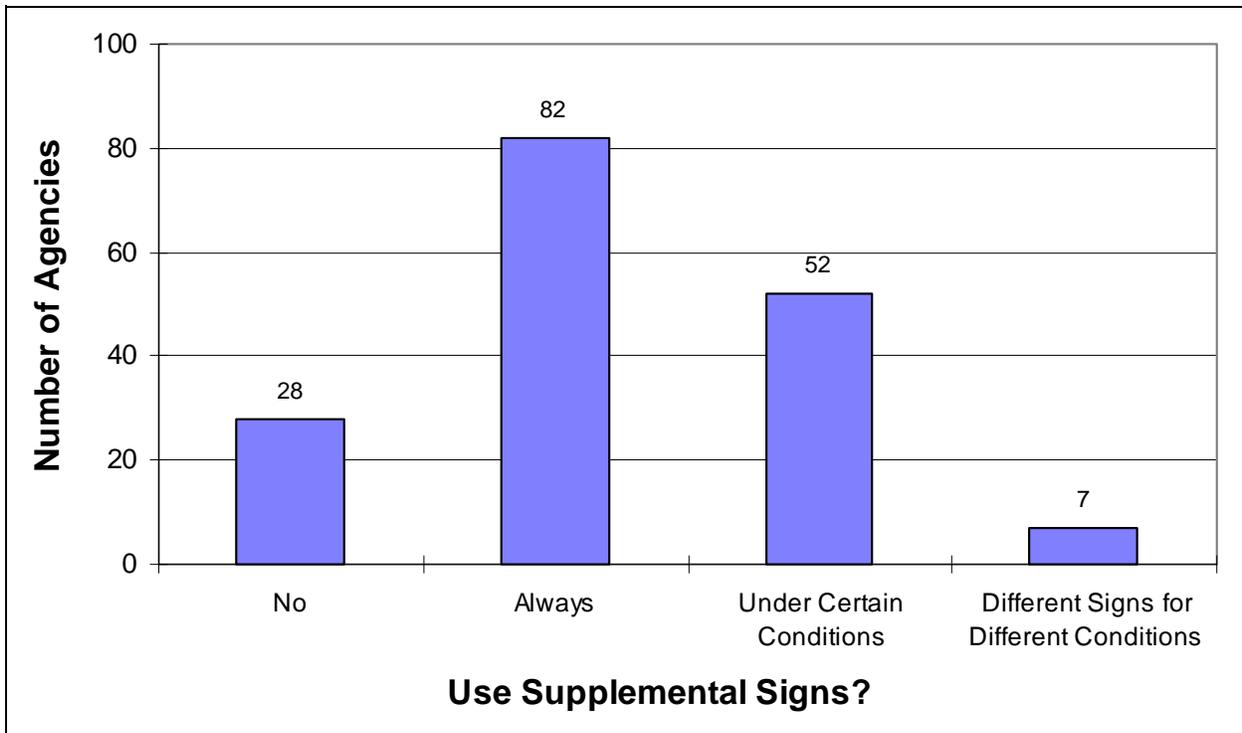


Figure 6 Use of Supplemental Signs with PPLT Signal Displays.

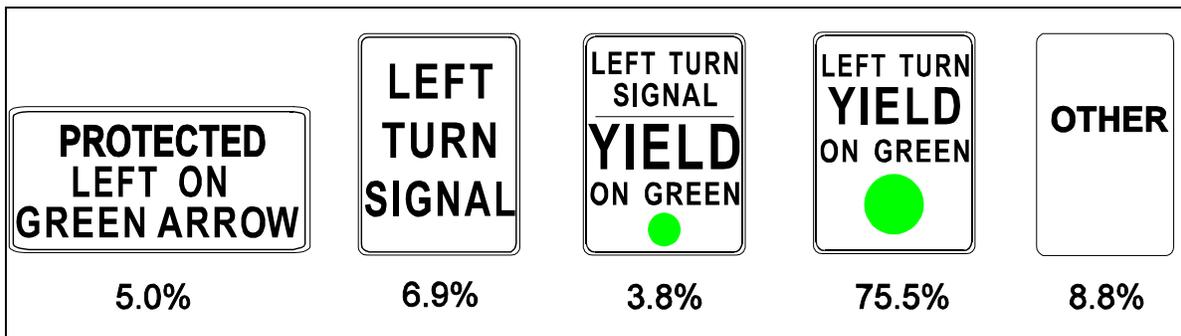


Figure 7 Supplemental Sign Usage.

Table 2 Other Supplemental Signs

Location	Supplemental Sign
Alaska	ONLY (green arrow) - YIELD ON (green ball)
Cupertino, CA	LEFT TURN YIELD ON FLASHING RED ARROW
Cupertino, CA	STOP THEN YIELD ON FLASHING RED ARROW
Monroe, LA	LEFT TURN PROTECTED ON ARROW ONLY
Maryland	LEFT TURN PERMITTED ON FLASHING RED AFTER STOP
Michigan	LEFT
Wyoming	YIELD ON GREEN BALL
Minnesota	LEFT TURN ON (green ball) MUST YIELD
Calgary, Alberta	YIELD ON SOLID GREEN

GEOMETRY AND PHASING

The next section of the survey asked each agency if they do anything different or unique with PPLT signal phasing, mounting locations, mounting type, or signal display arrangements in wide median intersections or in narrow right-of-way intersections where no median exists. Only 39 agencies (23 percent) indicated that they did something different with PPLT signal displays at wide median intersections while 32 agencies (19 percent) indicated that they did something different at narrow right-of-way intersections. At wide median intersections, the most commonly reported difference was the addition of another PPLT signal display, either median or far side pole mounted. The addition of another PPLT signal display may also require the repositioning of the other signal displays at the intersection. The only other commonly cited difference at wide median intersections was the elimination of PPLT signal phasing. Fifteen agencies indicated that they would not use PPLT signal phasing at wide median intersections.

At narrow right-of-way intersections and intersections with no medians, nearly all agencies who responded to this question indicated that they would not use PPLT signal phasing in these conditions. Each agency indicated that they would most likely change to split phasing if a narrow right-of-way exists. Two agencies indicated that they would relocate the signal displays to accommodate the narrow space and one agency indicated that they would change to Arlington Phasing.

Left-Turn Lane Geometry

The next survey section asked each agency to indicate the percentage of shared, exclusive, and combination left-turn lanes in their jurisdiction. The results, averaged across all agencies, are presented in Figure 8. On average, 89 percent of all left-turn lanes are exclusive, eight percent are shared, and three percent are a combination of exclusive and shared lanes. Only the states of

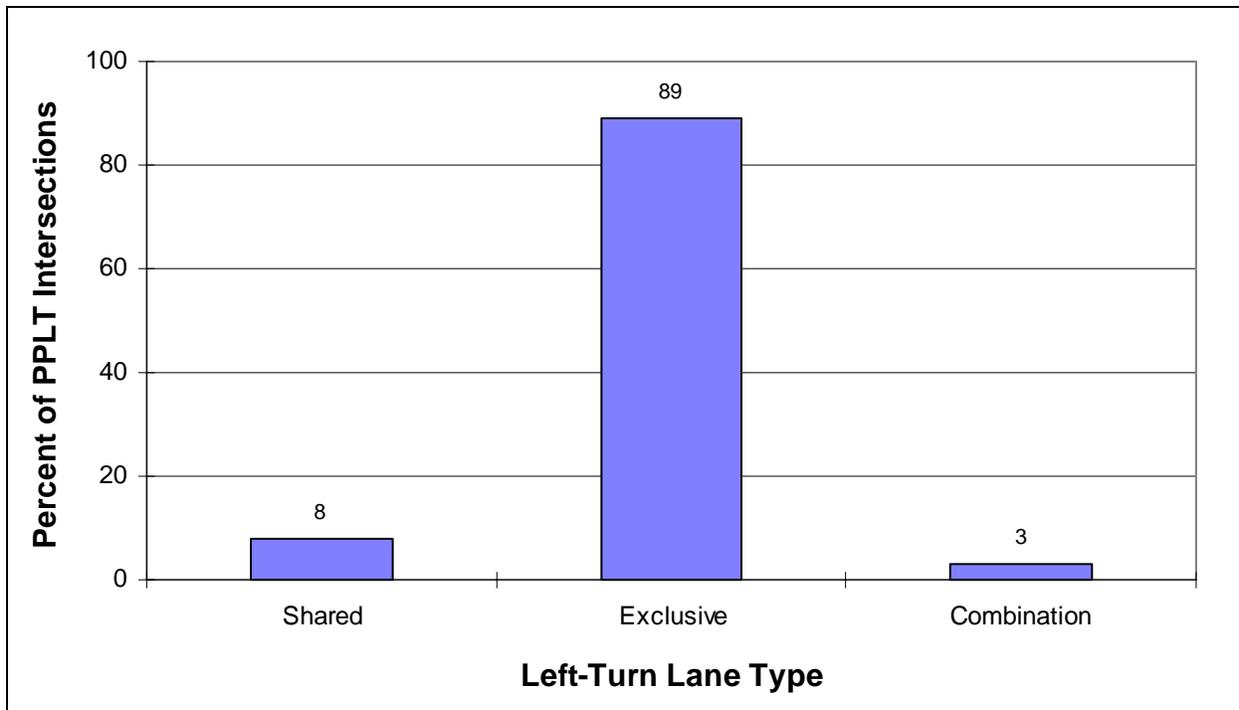


Figure 8 Left-Turn Lane Geometry Used with PPLT Signal Phasing.

Louisiana, Maine, Pennsylvania, and Rhode Island indicated that they have 50 percent or more shared left-turn lanes within their jurisdiction. In contrast, 53 agencies (32 percent) indicated that they have 100 percent exclusive left-turn lanes.

Left-Turn Phasing Sequence and Techniques

Each agency was asked to define the percentage of leading, lagging, and lead/lag PPLT signal phase sequencing used in their jurisdiction. The results are presented in Figure 9. Combining the results of all agencies, 83 percent of PPLT signalized intersections have a leading left-turn sequence, 11 percent a lagging sequence, and six percent a lead/lag sequence. When asked whether they use any special phasing or techniques to avoid the yellow trap problem, 95 agencies (57 percent) indicated that they did not. Eight agencies (5 percent) indicated that they used either Dallas or Arlington Phasing, 30 agencies (18 percent) indicated that they use exclusive left lead with PPLT lag, and 42 agencies (25 percent) indicated that they used some *other* method. Nearly all of the *other* methods were the inclusion of an anti-backup device in the controller that forced a side street green before returning to service a left-turn call. The results of the special phasing techniques are shown in Figure 10.

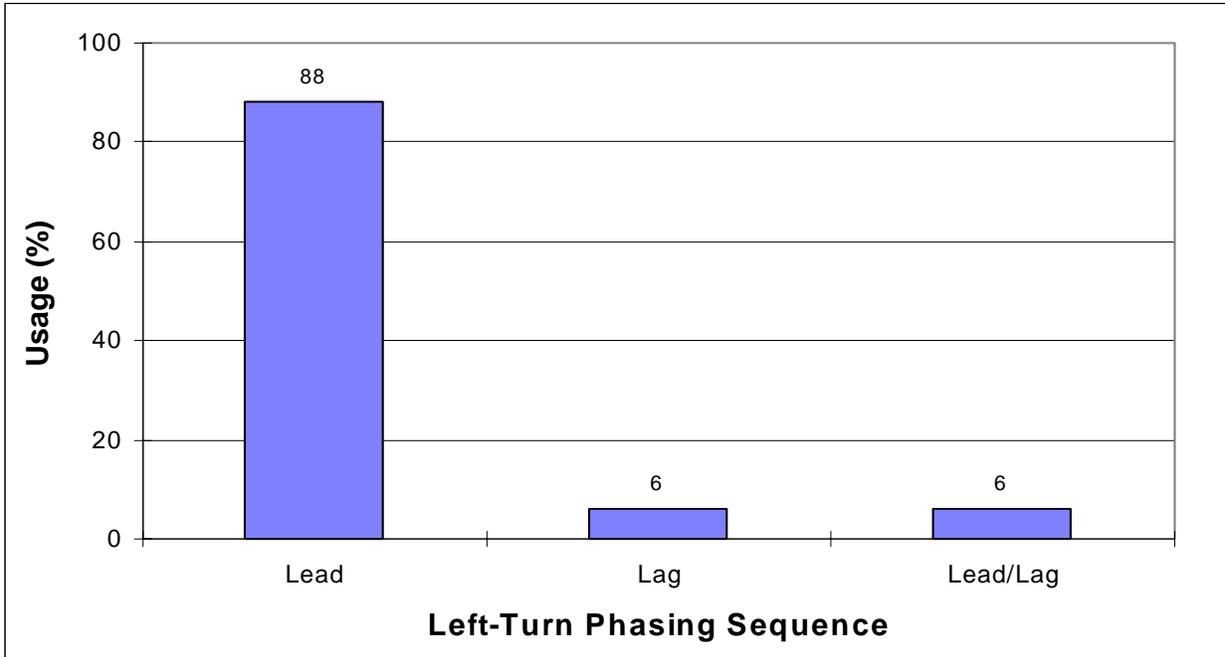


Figure 9 Left-Turn Sequence Used with PPLT Signal Phasing.

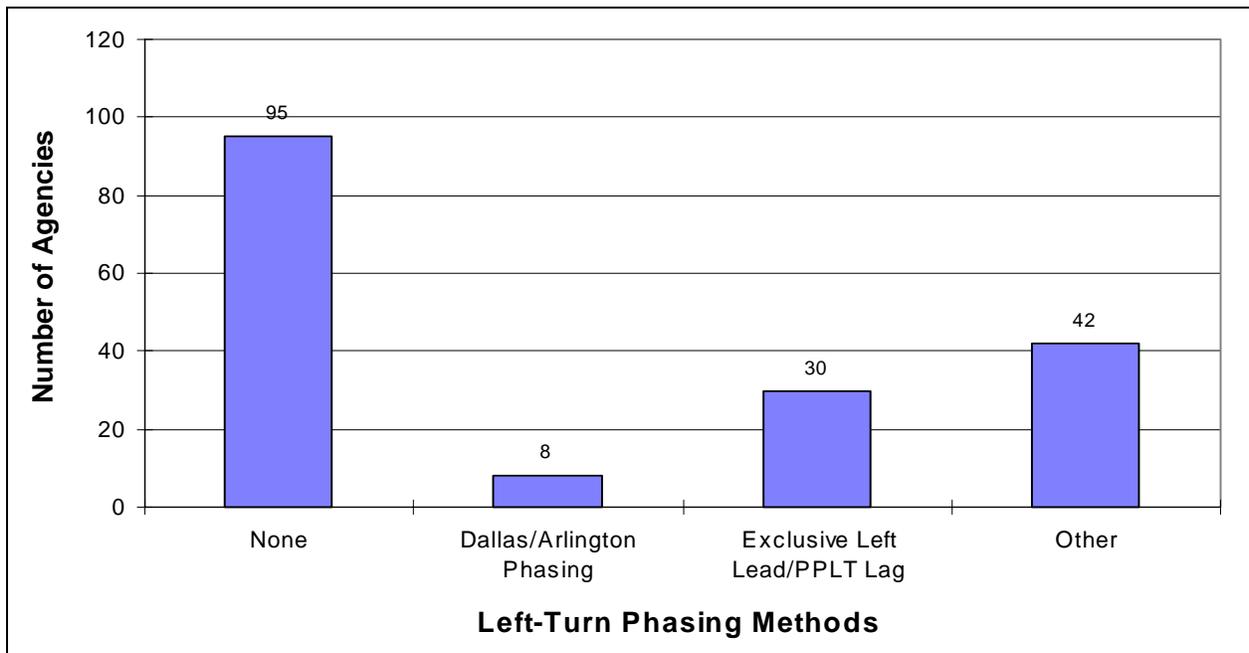


Figure 10 Special Phasing or Techniques Used to Avoid the Yellow Trap.

The final question in the survey asked each agency if there were any laws or ordinances within their jurisdiction that affects the use of PPLT signal phasing or mandate a specific signal display or signal indication. Only 12 of the responding agencies (7 percent) indicated that a law or ordinance required certain practices in the use of PPLT signal phasing. All of these agencies referred to state statutes or local ordinances that require either specific display types, display indications, or compliance with state manuals. The City of Milwaukee, Wisconsin was unique as they have an ordinance that prevents the traffic engineer from using PPLT signal phasing in dual left-turn lane situations, and prevents the use of left-turn phasing sequences that can produce the yellow trap.

SUMMARY

The agency survey quantified the attributes of more than 107,000 of the estimated 300,000 signalized intersections in the United States. Approximately 29 percent of these signalized intersections contain PPLT signal phasing. A five-section cluster display with a green ball permitted indication is used as the primary display at 63 percent of PPLT intersections. In addition, the five-section cluster display is predominantly used in 34 states. The next most commonly used PPLT signal display is the five-section vertical with a green ball permitted indication; however, this display represents only 19 percent of current usage.

Seven different display arrangements are used in PPLT applications, including both the five- and four-section horizontal, vertical, and cluster displays, and the three-section vertical display. There is little agreement as to the best location for mounting the overhead PPLT signal display as 52 percent of the responding agencies mount the PPLT display between the left-turn lane and through lane (lane line), 40 percent center the display on the left-turn lane, and 7 percent vary their mounting location. Many agencies have adopted standards for mounting placement including the exclusive or shared use of the PPLT signal display. Similarly, there was little consistency in signal display mounting methods as mast arm, pole, and span wire methods were all commonly used.

The MUTCD states that two signal displays are required for through movement application, one of which may also apply to the PPLT movement. There is little consistency across the U.S. in using a PPLT signal display as one of the two required through signal displays. Twenty-three percent of agencies do not use the PPLT signal display as a through display, 37 percent do, and 40 percent vary depending on the conditions at the intersection. When both a primary and secondary PPLT signal display was used, 62 percent used a secondary far side mounting location. Twenty percent were median mounted.

More than 98 percent of all PPLT signal displays include a green ball permitted indication. The flashing red ball, flashing red arrow, flashing yellow ball, and flashing yellow arrow permitted indications are also used, but in limited locations. Twenty percent of the responding agencies used bi-modal yellow and green arrow indications to reduce the size of their signal displays. A leading left-turn phasing sequence was used at 83 percent of PPLT intersections, followed by 11 percent for the lagging sequence and six percent for lead/lag. Eight agencies reported the use of Dallas or Arlington Phasing. Fifty-seven percent of responding agencies do nothing to prevent the yellow trap. Thirty of these agencies who do nothing to prevent the yellow trap use lead/lag left-turn signal phasing.

Exclusive left-turn lane geometry was used with PPLT operations at 89 percent of intersection reported. Shared lane geometry was used at approximately eight percent of intersection. Eighty-three percent of agencies reported the use of supplemental signs. There is no consistency in the use of supplemental signs as 17 percent of agencies do not use signs, 49 percent always use signs, and 34 percent use signs only in certain conditions. When signs are used, the MUTCD R10-12 sign is used more than 75 percent of the time; however, there are many other supplemental signs used, some of which may not be appropriate for PPLT applications.

Finally, there is little legal control over the use of PPLT signal phasing. Further, many states allow the local traffic engineer to select signal displays, display arrangement, signal phasing sequence, and display placement based on his or her professional judgement.

AUTHOR INFORMATION

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