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SAFETY IMPACTS OF FLASHING RED ARROW PROTECTED-PERMISSIVE LEFT-TURN CONTROL

Final Summary, BRTB Traffic Signal Subcommittee Meeting

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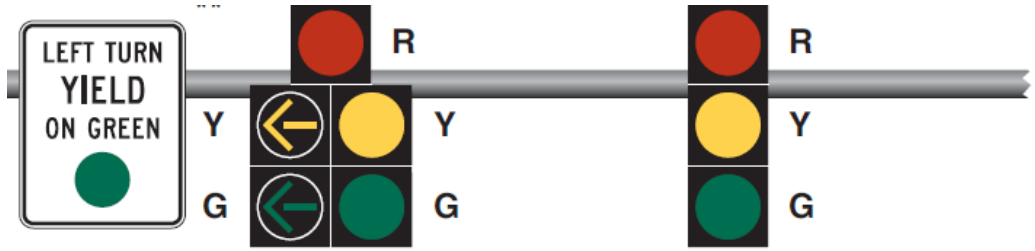
PROTECTED-PERMISSIVE LEFT-TURN PHASING (PPLT)

Standard "doghouse" arrangement with circular green



Balances safety and capacity

Exclusive/Permissive (EP) = Protected-Permissive (PPLT)

ADVANTAGES	DISADVANTAGES
• Improve LT safety over permissive only • Shorter cycle length • Less delay, queuing, congestion, emissions, fuel consumption than protected only	• Not as safe as protected phasing • Driver confusion potential • Yellow trap limits lead-lag phasing capability to T-intersections

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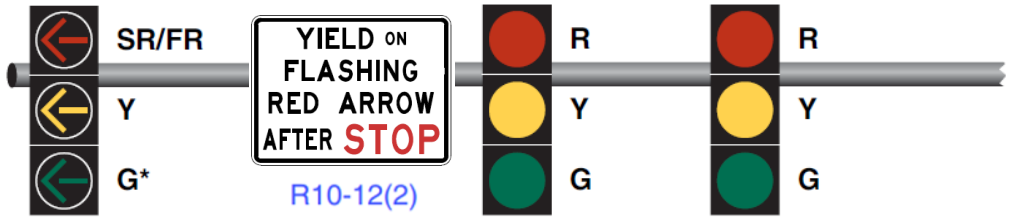
FLASHING RED ARROW (FRA) A VARIATION OF PPLT DISPLAY

NO FUNCTIONAL OR PHASING DIFFERENCES BETWEEN FRA PPLT AND "DOGHOUSE" PPLT



HISTORY
Used in Maryland since early 1980's

- Documented at 99 intersections
- Currently in use at 91 intersections owned by:
  - MDOT SHA (81)
  - Anne Arundel County (6)
  - Baltimore City (2)
  - Montgomery County (2)

FRA SPECIFIC ADVANTAGES

- Temporary or permanent mitigation of PPLT left turn crash pattern when protected-only left-turn phasing is not feasible
- No Yellow Trap
- Allows for lead-lag and twice-per-cycle left turn operations
- Can be protected by time of day, or by conditional statements in controller logic

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RESEARCH PROJECT OVERVIEW

If we convert existing left-turn display with circular green ("doghouse")to FRA – while maintaining PPLT phasing – how will it affect the crashes?

To date, no rigorous research has been found in the literature body to quantify the safety benefits of FRA PPLT compared to PPLT with circular green.

Our methodology fits in HSM and FHWA guidelines for Crash Modification Factor (CMF) development. Results are locally calibrated, remain robust to variations in before-after traffic volumes, and account for availability of crash data at each site.

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STUDY INTERSECTIONS

23 FRA-treated intersections with the following characteristics were selected for the study:

- 11 counties in six SHA Districts
- FRA installations between 2001-2016
- 3- or 4-leg configurations
- Main road speed limit: 30-55 mph
- Main road AADT: 17000-51000
- Number of opposing thru lanes 1-3
- Crash Data:
  - 2 to 4 Years for "Before" condition
  - 9 months to 8 years for "After" condition

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STUDY INTERSECTIONS - DETAILS

No.	Intersection	County	Year FRA Installed	Speed Limit (mph)	Opposing Thru Lanes	Major Road AADT	Crash Data (Years)		After/Before Crash Ratios					
									Left-turn		Rear-End		Total	
							Before	After	All	Injury	All	Injury	All	Injury
1	MD 170 & Amtrak Way	AA	2005	45	2	45394	3	6	0.21	0.13	1.38	3.5	0.21	0.13
2	MD 173 & Brandon Shore Rd	AA	2001	50	2	27221	3	6	0.2	0.18	1.5	1.5	0.2	0.18
3	MD 150 & Kingston Rd	BL	2012	35	2	38571	3	4	0.23	0.3	3.75	5.25	0.23	0.3
4	US 1 & Mt Vista Rd.	BL	2013	50	2	22651	3	3	0.83	0.33	1.3	0.7	0.83	0.33
5	MD 140 & Valley Centre Dr	BL	2016	40	2	39601	4	0.75	1.33	0.8	0	0	1.33	0.8
6	MD 140 & Walmart	BL	2016	40	2	39601	4	0.75	4	1.33	2	0	4	1.33
7	MD 404 & Deep Shore Rd	CL	2015	50	2	24268	3	2	0.25	0.17	0.75	0	0.25	0.17
8	MD 404 & MD 328	CL	2015	55	2	28299	3	2	0.9	0.64	1.5	0	0.9	0.64
9	MD 26 & Johnsville Rd	CR	2012	45	2	25970	3	4	0.94	0.88	1.13	1	0.94	0.88
10	MD 27 & Twin Arch Rd	CR	2016	50	2	20970	3	2	0.54	0.8	1	0.21	0.54	0.8
11	US 40 & MD 7C/Belvidere Rd	CC	2009	55	2	25151	3	6	1.18	1.03	1	0.67	1.18	1.03
12	MD 85 & Guilford Rd	FR	2007	40	2	26071	3	8	0.56	0.38	0.38	0	0.56	0.38
13	MD 103 & Brightfield Rd	HW	2010	40	1	12586	3	6	0.63	0.3	0.67	0	0.63	0.3
14	MD 108 & Lark Brown Rd	HW	2012	45	2	21300	3	4	0.14	0.2	0.75	0.5	0.14	0.2
15	US 40 & Marriottsville Rd	HW	2008	55	2	17000	3	7	0.66	0.97	1.29	0.29	0.66	0.97
16	US 1 & Guilford Rd	HW	2011	50	2	38190	3	6	0.92	2.5	3	1.5	0.92	2.5
17	MD 117 & MD 118	MG	2009	30	2	24972	3	6	0.75	0.44	1.5	1	0.75	0.44
18	MD 28 & MD 182	MG	2012	45	2	15700	3	4	0.75	0.78	0.3	0.38	0.75	0.78
19	MD 450 & I-495 SB Ramp	PG	2015	35	2	51182	3	7	0.29	0.18	0.21	0	0.29	0.18
20	MD 8 & MD 18	QA	2009	40	2	15873	3	7	0.48	1.37	0	0	0.48	1.37
21	US 50 & Dutchmans Ln	TB	2009	45	2	35812	2	3	0.44	0.48	1.73	1.2	0.44	0.48
22	US 50 & MD 328	TB	2012	35	3	35812	3	4	0.38	1.13	0.42	0.26	0.38	1.13
23	US 50 & MD 331	TB	2012	35	3	35812	3	4	0.71	0.89	1.13	0.75	0.71	0.89

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METHODOLOGY

Estimation of the Safety Performance Function (SPF) parameters:

- A control sample of 20 signalized intersections with "traditional" PPLT was established.
- 6 years of crash data and corresponding traffic volume records.

- The left-turn crashes and total crashes had FRA control not been implemented were estimated as a function of traffic volume using the following equations:

Crash Type Specific SPF Parameters

	Crash Model	Parameter	β	SE	P-Value
(a) SPF parameter estimates, crashes (all severities)	Left-turn Crashes	Intercept (a)	-9.293	1.99	<.0001
		Ln AADT Major Road Left-turn	0.6359	0.194	0.001
		Ln AADT Minor Road	0.5316	0.258	0.0392
		Over-Dispersion (k)	0.2021		
	Total Crashes	Intercept (a)	-6.984	1.991	0.0005
		Ln AADT Major Road	0.4944	0.169	0.0035
		Ln AADT Minor Road	0.4076	0.127	0.0013
		Over-Dispersion (k)	0.1429		
(b) SPF parameter estimates, injury crashes	Left-turn Crashes	Intercept (a)	-6.11	2.137	0.0042
		Ln AADT Major Road Left-turn	0.8385	0.277	0.0025
	Total Crashes	Intercept (a)	-12.28	3.067	<.0001
		Ln AADT Major Road	0.6809	0.26	0.0087
		Ln AADT Minor Road	0.7571	0.195	0.0001
		Over-Dispersion (k)	0.498		

$$\text{Estimated Left-turn Crashes} = \exp[a + \beta_1 * \ln(\text{AADT}_{\text{Major Road Left-turn}}) + \beta_2 * \ln(\text{AADT}_{\text{Minor Road}})]$$

$$\text{Estimated Total Crashes} = \exp[a + \beta_1 * \ln(\text{AADT}_{\text{Major Road}}) + \beta_2 * \ln(\text{AADT}_{\text{Minor Road}})]$$

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METHODOLOGY (CONTINUED)

Selected steps in the Empirical Bayes estimation procedure:

- Compute the number of crashes that would have taken place in the after period had FRA control not been implemented:

$$B = m_a * y_a$$

where, y_a=number of years in the after period

- Compute the variance for the number of crashes that would have taken place had FRA control not been implemented:

$$Var(B) = m_b * \frac{(R * y_a)^2}{\left[\left(\frac{k}{P_a}\right) + y_b\right]}$$

- Determine the crash-type specific CMFs and the variance in the CMF value

$$CMF = \frac{\left[\frac{\sum A}{\sum B}\right]}{\left[1 + \frac{var \sum B)}{(\sum B)^2}\right]}$$

$$var(CMF) = \frac{\left[\left(\frac{var \sum A)}{(\sum A)^2}\right) + \left(\frac{var \sum B)}{(\sum B)^2}\right)\right]}{\left[1 + \frac{var \sum B)}{(\sum B)^2}\right]^2}$$

A resulting CMF value of less than 1 indicates the modification reduced the crash frequency at an intersection.

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RESULTS

Crash Modification Factor (CMF): unbiased estimate of index of effectiveness. It represents a factor of change in crash frequency resulting from a countermeasure.

Here, the treatment is changing the display on PPLT from 5-section signal head arrangement with circular green to PPLT on 3-section signal head with Flashing Red Arrow.

	Left-turn	Left-turn Injury	Total	Total Injury
CMF	**0.53**	**0.63**	**0.75**	**0.71**
Standard Error	0.054	0.06	0.047	0.05

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DISCUSSION

- Overall, the results show a 47% expected decrease in left-turn crash frequency and 25% decrease in the total crash frequency when PPLT with circular green is converted to PPLT with FRA.
- Left-turn injury crashes drop by 37%, and total injury crashes decrease 29%
- General trend of significant crash reduction is not disrupted by FRA installations with short "after" crash history. Recent FRA deployments will be monitored to fully evaluate the long-term FRA impact there.
- AADT increase does not seem to have a negative impact on the number of crashes. Intersections with the highest AADT are among those with most significant safety improvement.
- Posted speed does not seem to have a distinguishable effect on safety (for example, some of the worst and best performing intersections have same posted speed and similar AADT)
- Location (county) of a site does not reveal an effect on safety pattern

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SUMMARY

- Application of FRA PPLT alleviates a LT safety problem while maintaining operational efficiency of a traditional PPLT display with circular green
- When conversion to fully protected phasing not feasible or easily attainable, FRA can be used as a temporary or a permanent countermeasure
- Allows for greater flexibility in phase sequence than doghouse PPLT: can use FRA with lead-lag or twice-per-cycle LT phasing
- Restricting LT operations to protected-only by time of day possible with FRA
- To address unique LT safety problems, FRA display allows for cycle-by-cycle suppression of the permissive LT with advanced controller logic

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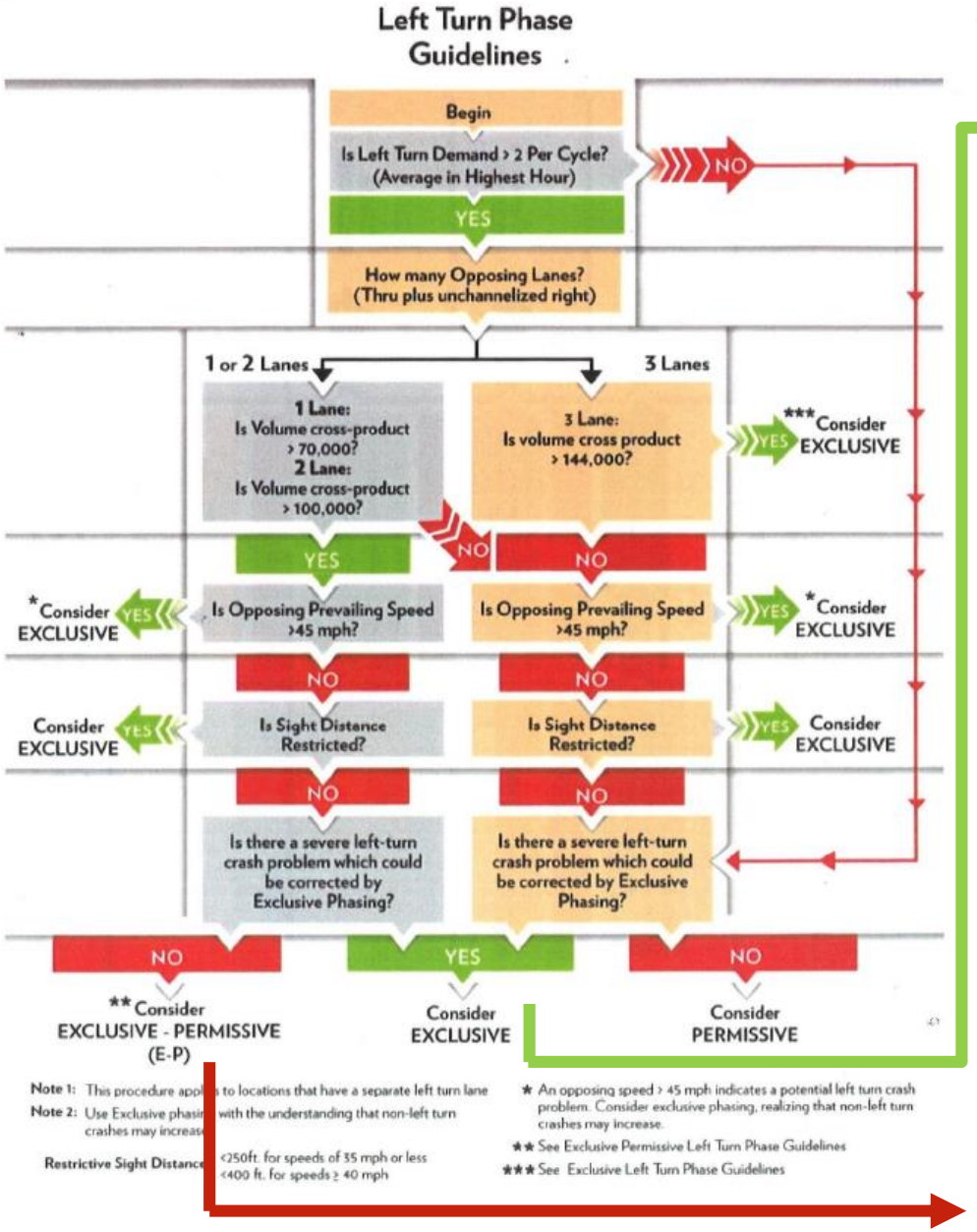
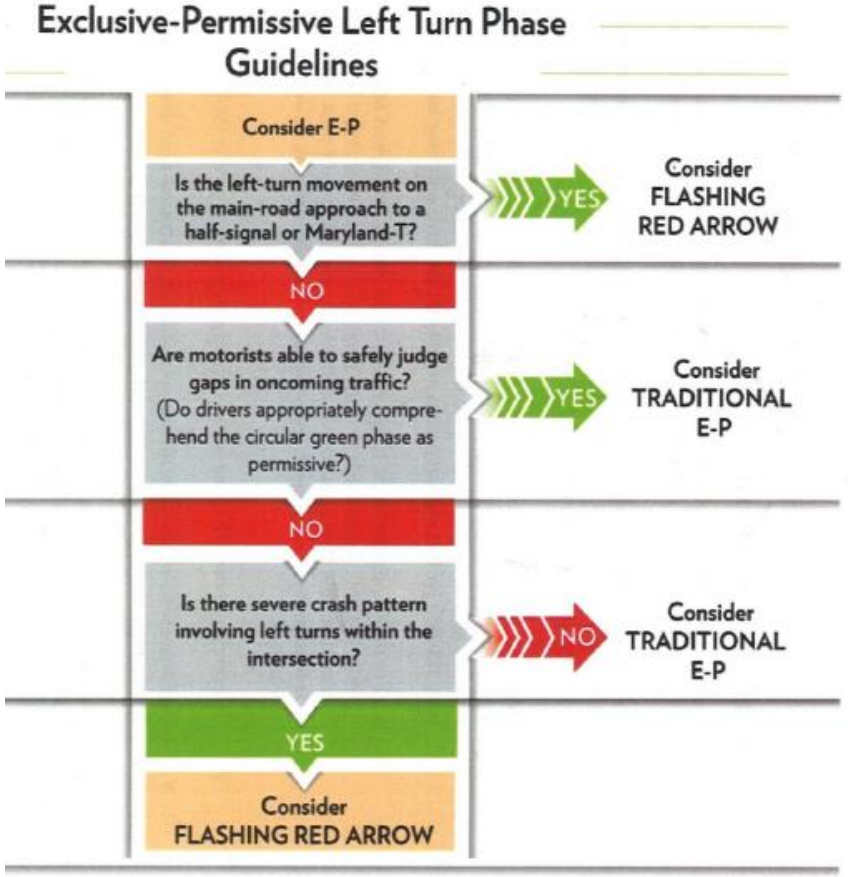
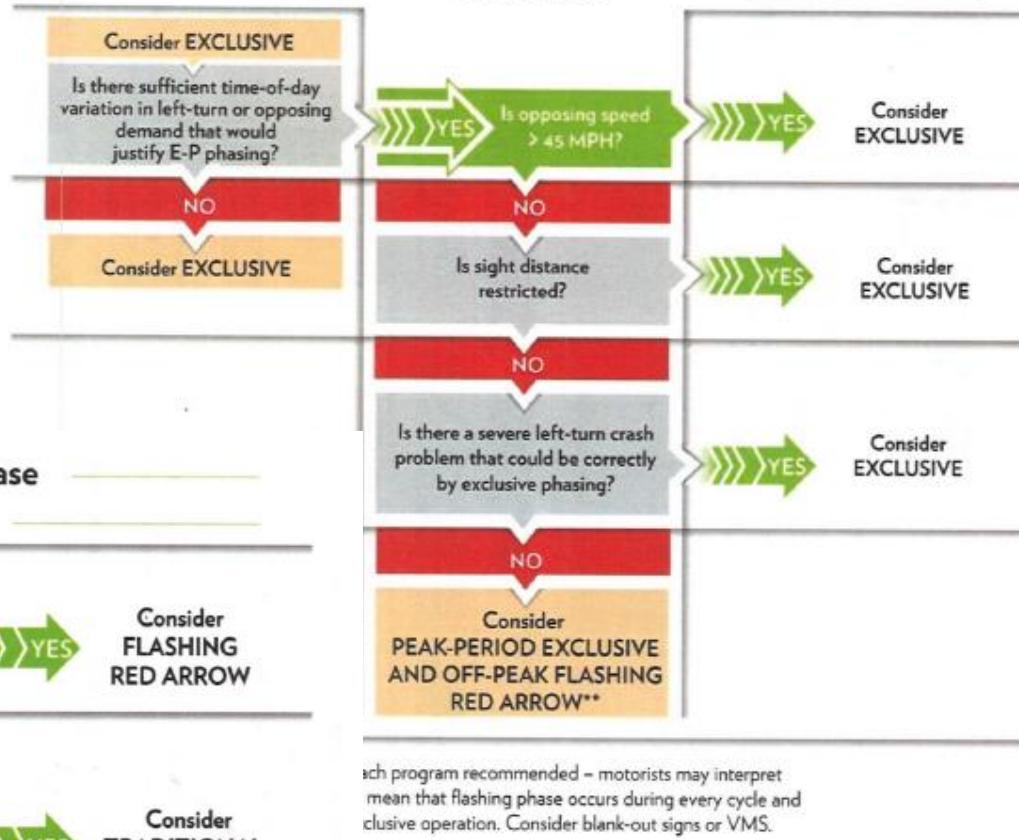
UPDATED LEFT-TURN PHASING GUIDELINES







ach program recommended – motorists may interpret
mean that flashing phase occurs during every cycle and
clusive operation. Consider blank-out signs or VMS.

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QUESTIONS?

Have a detailed question? Need the full report?

Please contact:

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