SAFETY EVALUATION OF FLASHING YELLOW ARROW TREATMENT

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ABSTRACT

This paper presents the results of an evaluation of the flashing yellow arrow (FYA) treatment using data from signalized intersections in Nevada, North Carolina, Oklahoma, and Oregon. The evaluation method was an empirical Bayes before-after analysis. The treatments were divided into seven categories depending on the phasing system in the before period (permissive, protected-permissive, or protected), phasing system in the after period (FYA permissive or FYA protected-permissive), the number of roads where the FYA was implemented (major, minor, or both), and the number of legs at the intersections (three or four). The first five categories involved permissive or protected-permissive phasing in the before period. Intersections in these five treatment categories experienced a reduction in the primary target crashes under consideration: left-turn crashes and left turn with opposing through crashes (both at the intersection level). The reduction ranged from 15 to 50 percent, depending on the treatment category. Intersections in categories 6 and 7 had at least one protected left-turn phase in the before period, and after phasing had flashing yellow arrow protected-permissive left-turn phase without time of day operation (category 6) and with time of day operation (category 7). Consistent with results from previous studies, these intersections experienced an increase in left-turn and left turn with opposing through crashes. Agencies typically use categories 6 and 7 for capacity improvements rather than safety, but the implications for safety are important.

BACKGROUND

The primary intent of the flashing yellow arrow (FYA) for permissive left-turn movements at signalized intersections is to help avoid confusion for drivers turning left on a permissive circular green signal. The concern is that drivers turning left on a permissive circular green signal indication might mistake that indication as implying the left turn has the right of way over opposing traffic, especially under some geometric conditions. This research examined the safety impacts of FYA using data from sites in Oklahoma, Oregon, Nevada, and North Carolina. The objective was to estimate the safety effectiveness of this strategy as measured by crash frequency. The primary target crash type is left-turn crashes and left turn opposing through (LTOT) vehicles. However, changes in signal timing sometimes accompany changes in signal phasing, altering the green time that is available for through movements, and as a result, could affect the propensity for rear-end and angle crashes. Due to this, the evaluation included the following crash types:

- Total Intersection Crashes.
- Intersection Injury and Fatal Crashes.
- Intersection Rear-End Crashes.
- Intersection Angle Crashes.
- Intersection Left-Turn Crashes.
- Intersection LTOT.

The evaluation of overall effectiveness included the consideration of the installation costs and crash savings in terms of the B/C ratio. This paper provides a brief overview of the methodology, data, and the results. Further details are available in an upcoming FHWA report (*1*).

OVERVIEW OF METHODOLOGY

This evaluation uses the EB methodology for observational before-after studies. When planning a before-after safety evaluation study, it is vital to ensure that enough data are included to statistically detect the expected change in safety. Even though those designing the study do not know the expected change in safety in the planning stage, it is still possible to make a rough determination of how many sites the study will require, based on the best available information about the expected change in safety. For a detailed explanation of sample size considerations, as well as estimation methods, see chapter 9 of Hauer (*2*). In this study, the methods from Chapter 9 of Hauer (*2*) were used to determine the number of sites that are needed to statistically detect the expected change in safety.

DATA AND TREATMENT CATEGORIES

Nevada, North Carolina, Oklahoma, and Oregon provided data for this study. These States also provided data on details about the intersections, traffic volumes on the major and minor roads, and crashes for both installation and reference sites. They also provided crash injury severities relative to the KABCO scale, in which K represents fatal injury, A represents incapacitating injury, B represents non-incapacitating injury, C represents possible injury, and O represents property damage only. The evaluation included 307 treated sites and 438 reference sites from these four States.

Seven treatment categories were investigated. The literature review revealed that the before condition could have a significant impact on safety. For example, if a State introduces the FYA as a replacement for protected left-turn phasing, it could lead to an increase in left turn crashes. For this reason, based on the phasing system before and after the implementation of the FYA, seven treatment categories were identified. Table 1 shows the seven treatment categories.

Table 1. Treatment categories.

Category	Before Phasing	After Phasing	Legs	Sites
1	Traditional PPLT	FYA PPLT on one road	3	40
2	Traditional PPLT	FYA PPLT on one road	4	136
3	Traditional PPLT	FYA PPLT on both roads	4	64
4	Permissive or Traditional PPLT	FYA permissive on one road	4	25
5	Permissive	FYA permissive on one road	4	12
6	At least one protected phase	FYA PPLT without TOD	4	18
7	At least one protected phase	FYA PPLT with TOD	4	12

Note: PPLT represents protected-permissive left turn operation; TOD represents Time of Day operation.

SAFETY PERFORMANCE FUNCTIONS

The EB methodology uses SPFs to estimate the safety effectiveness of this strategy. Generalized linear modeling was used to estimate model coefficients assuming a negative binomial error distribution, which is consistent with the state of research in developing these models. The independent variables included the following:

- Major road AADT.
- Minor road AADT.
- Number of legs (three or four legs) (this is a categorical variable).
- Left turn phasing. The coding for this categorical variable is based on the maximum left turn protection at an intersection (protected, protected-permissive, or permissive).
- Number of through lanes on the major road.
- Presence/absence of median on the major road.
- Number of approaches with left turn lanes.

The variables are included in a log-linear form as follows:

$$Y = \exp\left(a_0 + a_1 X_1 + a_2 X_2 + \cdots .. a_n X_n\right)$$

Where:

a_0 = the intercept.
a_1 through a_n = the coefficients for independent variables X_1 through X_n.
Y = number of predicted crashes from the SPF

The project team estimated separate SPFs for each crash type. After estimating the SPFs, the project team estimated annual SPF multipliers.

RESULTS AND CONCLUSIONS

Table 2 through Table 8 show the crash modification factors (CMFs) for these treatment categories for the six crash types. The tables show the crash type, the number of crashes in the after period, the expected number of crashes had the treatment not been implemented, the CMF, and the standard error of the CMF. The first five treatment categories involved permissive or protective-permissive left turn (PPLT) in the before period. Intersections in these five treatment categories experienced a reduction in the primary target crashes under consideration: left-turn crashes at the intersection level and LTOT crashes at the intersection level. The reduction ranged from 15 to 50 percent, depending on the treatment category. Intersections in categories 6 and 7 had at least one protected left-turn phase in the before period. Consistent with results from previous studies, these intersections experienced an increase in left-turn and LTOT crashes. Agencies typically use categories 6 and 7 for capacity improvements rather than safety, but the implications for safety are important.

Table 2. CMFs for category 1 (3 legs, 40 sites).

Crash Type	Actual After	Expected After	CMF	SE of CMF
Total	363	427.2	0.849*	0.053
Injury and fatal (KABC)	129	162.7	0.791*	0.080
Rear-end (RE)	148	169.4	0.871	0.084
Angle (ANG)	49	63.5	0.768	0.122
Left-turn (LT)	80	99.0	0.804	0.106
Left-turn with opposing through movements (LTOT)	60	70.4	0.846	0.131

Note: LTOT crash counts were not available in Nevada. For LTOT crashes, 37 sites were used.
* denotes CMFs statistically different from 1.0 at the 95-percent confidence level.

Table 3. CMFs for category 2 (4 legs, 136 sites).

Crash Type	Actual After	Expected After	CMF	SE of CMF
Total	1951	2194.8	0.889*	0.027
KABC	722	900.3	0.801*	0.038
RE	753	851.4	0.884*	0.042
ANG	486	505.4	0.960	0.054
LT	413	552.9	0.746*	0.047
LTOT	200	324.1	0.615*	0.055

Note: LTOT crash counts were not available in Nevada. For LTOT crashes, 88 sites were used.
* denotes CMFs statistically different from 1.0 at the 95-percent confidence level.

Table 4. CMFs for category 3 (4 legs, 64 sites).

Crash Type	Actual After	Expected After	CMF	SE of CMF
Total	750	916.4	0.818*	0.036
KABC	286	365.3	0.782*	0.055
RE	306	338.6	0.902	0.066
ANG	207	233.7	0.885	0.068
LT	185	296.2	0.624*	0.053
LTOT	75	147.6	0.507*	0.064

Note: LTOT crash counts were not available in Nevada. For LTOT crashes, 31 sites were used.* denotes CMFs statistically different from 1.0 at the 95-percent confidence level.

Table 5. CMFs for category 4 (4 legs, 25 sites).

Crash Type	Actual After	Expected After	CMF	SE of CMF
Total	409	410.0	0.997	0.058
KABC	124	153.1	0.808*	0.082
RE	159	157.9	1.005	0.093
ANG	94	90.9	1.030	0.123
LT	55	75.1	0.729*	0.109
LTOT	39	52.9	0.733*	0.130

Note: * denotes CMFs statistically different from 1.0 at the 95-percent confidence level.

Table 6. CMFs for category 5 (4 legs, 12 sites).

Crash Type	Actual After	Expected After	CMF	SE of CMF
Total	192	209.3	0.915	0.078
KABC	74	93.6	0.787*	0.104
RE	84	68.0	1.227	0.165
ANG	23	30.2	0.753	0.173
LT	42	68.2	0.612*	0.105
LTOT	30	54.3	0.548*	0.111

Note: * denotes CMFs statistically different from 1.0 at the 95-percent confidence level.

Table 7. CMFs for category 6 (4 legs, 18 sites).

Crash Type	Actual After	Expected After	CMF	SE of CMF
Total	378	359.1	1.051	0.065
KABC	120	118.3	1.011	0.110
RE	152	164.0	0.925	0.087
ANG	57	55.8	1.014	0.159
LT	82	52.5	1.551*	0.219
LTOT	71	36.8	1.910*	0.299

Note: * denotes CMFs statistically different from 1.0 at the 95-percent confidence level.

Table 8. CMFs for category 7 (4 legs, 12 sites).

Crash Type	Actual After	Expected After	CMF	SE of CMF
Total	518	531.6	0.974	0.050
KABC	178	163.1	1.089	0.095
RE	227	250.9	0.903	0.068
ANG	96	81.8	1.169	0.141
LT	44	34.4	1.267	0.226
LTOT	30	25.7	1.151	0.242

A crash modification function (CMFunction) were estimated using data from treatment category 2 to determine if the CMF is a function of site characteristics such as expected crashes in the before period, and the State of installation. The estimated CMFunction for LTOT crashes for treatment category 2 is given below:

$$CMF = 0.694 \times (Exp\ bef\ per\ year)^{-0.2626}$$

Where:

Exp bef per year = the EB expected LTOT crashes per year at the intersection level in the before period (i.e., before the FYA was implemented).

Economic Analysis

Economic analysis were undertaken for treatment categories 1 through 5. Treatment categories 6 and 7 (change from protected to FYA PPLT) are implemented for reasons other than safety, and as a result, were not included in the economic analysis.

For the benefit calculations, the most recent FHWA mean comprehensive crash costs by crash severity were used (*3*). These costs are based on 2001 crash costs, and the unit cost (in 2001 dollars) for injury and fatal crashes and PDO crashes in urban areas was $91,917 and $7,068, respectively. These were updated to 2015 dollars by applying the ratio of the USDOT 2015 value of a statistical life of $9.4 million to the 2001 value of $3.8 million (*4*). Applying this ratio of 2.47 to the unit costs resulted in an aggregate 2015 unit cost of $227,744 for injury and fatal crashes and $17,513 for PDO crashes. Sensitivity analysis were conducted based on the USDOT 2015 document, and this led to a minimum and maximum value for the benefit values, and for the B/C ratio.

For treatment cost, Oklahoma indicated that the installation cost was about $6,500 for a 4-leg intersection, i.e., about $1,625 per approach leg. In a recent study in Illinois (*5*), installation cost was assumed to be $6,000 per approach leg. The higher installation cost from Illinois was assumed to get a conservative estimate for the B/C ratio. In using this cost, it was assumed that the signal pole is structurally adequate to accommodate the retrofit. In addition, it was also assumed that there would be no additional maintenance costs for the FYA compared to traditional phasing systems. For these calculations, the discount rate (as a decimal) and assumed to be 0.07, and the expected service life (years) was assumed to be 10 years. The B/C ratio was calculated as the ratio of the annual crash savings to the annualized treatment cost. Table 9 provides the results.

Table 9. Results of economic analysis.

Treatment Category	Economic Benefits due to crash reduction (per intersection per year)	Annualized treatment cost (per intersection per year)	BC Ratio (Mean)	BC Ratio (Min, Max)
Category 1	$ 72,010	$854	84:1	(46:1, 116:1)
Category 2	$ 117,626	$1,709	69:1	(38:1, 95:1)
Category 3	$ 191,990	$3,417	56:1	(31:1, 78:1)
Category 4	$ 245,410	$1,709	144:1	(79:1, 198:1)
Category 5	$ 152,535	$1,709	89:1	(49:1, 123:1)

LIMITATIONS

Left-turn volumes were not available and, as a result, the evaluation could not include them. The evaluation focused on intersection level crashes instead of approach level crashes, because we could not reliably obtain approach level crashes from the coded crash reports.

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